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TO
DECISION



PRINCETON

School of Engineering
 and Applied Science

Engineering a difference

As I step into the role of dean, I am honored and inspired to think about this great university, the extraordinary School of Engineering and Applied Science within it, and the combined power they have to make profound, positive differences in the world. This power derives from the very qualities that set us apart from any other institution: our people and our culture. Our faculty members focus on fundamentals, the rigorous science that underlies everything we do, while maintaining a line of sight to the ultimate impact of our work in service of society. By collaborating seamlessly across all parts of the University, we pursue, and prepare our students to pursue, long-term breakthroughs that will power our world, solve environmental problems, prevent and treat disease, improve and secure our information technology infrastructure, and create many other lasting solutions to societal challenges.

I am extremely grateful for the work of my predecessor, H. Vincent Poor *77, in leading the engineering school over the last decade. I am eager to continue and accelerate that progress, bringing together a diverse population of faculty, students, postdocs, and other collaborators, and providing them the needed resources to do their best work. Chief among those resources must be new, flexible, multidisciplinary working spaces that support 21st-century science, open-ended tinkering, design thinking, and entrepreneurship.

This issue of EQuad News highlights just one of the key areas of growth we will pursue: the tremendous promise of data and information science, an area that spans all disciplines and has enormous implications for society.

I look forward to working with all of you – colleagues at Princeton and around the world, alumni, government, and industry partners, entrepreneurs, and our wonderful students and postdocs – as together we explore, build, and create our way to a better future.



Photo by David Kelly Crow

Emily Carter

Dean
Gerhard R. Andlinger Professor in Energy
and the Environment
Professor of Mechanical and Aerospace Engineering
and Applied and Computational Mathematics

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Photo by David Kelly Crow

EMILY CARTER NAMED DEAN OF ENGINEERING SCHOOL

Emily Carter, a Princeton faculty member since 2004 and founding director of the University's Andlinger Center for Energy and the Environment, became dean of the School of Engineering and Applied Science on July 1.

Carter is the Gerhard R. Andlinger Professor in Energy and the Environment and a professor of mechanical and aerospace engineering and applied and computational mathematics. She has earned wide recognition for fundamental research contributions as well as for her vision for harnessing science and policy to produce lasting solutions to societal problems, including those of energy and the environment.

"I'm delighted that Professor Emily Carter has agreed to become the next dean of the School of Engineering and Applied Science," President Christopher L. Eisgruber '83 said in announcing the appointment in April. "She is a brilliant scholar, a capable and proven administrator, and a dynamic champion for engineering at Princeton. Emily's vision and leadership will make her a superb dean at a time when the University is planning major investments in its engineering school."

Carter succeeds H. Vincent Poor *77, the Michael Henry Strater Professor of Electrical Engineering, who served as dean since

2006 and returned to full-time teaching and research.

As director of the Andlinger Center since 2010, Carter led a critical period of growth culminating with the May 18 dedication of the new Andlinger Center for Energy and the Environment building. Created in 2008 and named in recognition of a \$100 million gift from Gerhard Andlinger '52, the center combines science and engineering with public policy and architecture to create solutions to problems of energy and the environment.

Carter has overseen the hiring of the center's staff along with eight faculty members who were jointly appointed with a range of academic departments, the creation of a corporate affiliates program, the start of an undergraduate certificate program, and the launch of a series of technology briefings aimed at policymakers and interested citizenry. She also has spearheaded initiatives in research innovation funding, a speaker series, and internship programs.

"I am immensely grateful to my colleagues and the University administration for their faith in me to lead the already world-class School of Engineering and Applied Science to new heights," Carter said. "Having spent the last six years building the Andlinger Center – from

Emily Carter, who became dean of Princeton University's School of Engineering and Applied Science July 1, was founding director of the Andlinger Center for Energy and the Environment. She gave a talk at the center's Building Opening Celebration and Symposium May 19.

EMILY CARTER NAMED DEAN OF ENGINEERING SCHOOL *(continued from page 1)*

its people to its activities to bricks and mortar – I intend to bring the same collaborative philosophy to Princeton engineering as a whole.”

Provost David S. Lee '99 said he is eager to work with Carter in her new capacity. “Her intellect as a distinguished scientist and her proven experience as an administrator will be crucial to the ongoing strategic thinking about investments in the engineering school in the coming years,” Lee said. “At the same time, as she has been for the Andlinger Center, Professor Carter will be an outstanding representative for the University, advocating for how Princeton engineering, through its teaching and research mission, can contribute to the world and address societal problems of the 21st century.”

Among her many honors, Carter was elected in 2008 to the National Academy of Sciences and the American Academy of Arts

and Sciences and was elected this year to the National Academy of Engineering. She has written more than 300 scientific publications and delivered over 500 invited and plenary lectures worldwide.

“The most challenging problems society faces are thorny, complex, and large, which no single expert will solve on his or her own,” Carter said. “Both in my own research activities and in the Andlinger Center, I’ve sought to catalyze interdisciplinary teamwork as I firmly believe that is how many, if not most, future breakthroughs will occur. But disciplinary cores must be strongly supported as well. At Princeton, we do both. I don’t say lightly that Princeton is – bar none – the best place I have ever seen at fostering interdisciplinary work, at every level. It is a major reason for our outsized impact in the world.” –**Steven Schultz**

Photo by David Kelly Crow



A three-day symposium May 18 to 20 celebrated the opening of the new building for the Andlinger Center for Energy and the Environment. The symposium featured talks by Andlinger Center faculty, who highlighted recent research advances, as well as by academic, government, and industry leaders outlining their visions for the future of energy and the environment. A panel discussion, shown above, covered the center’s preparation of regular written briefings on energy policy and technology.

PROFESSORS LEAD NASA SCIENCE TEAM PROBING UNIVERSE AND PLANETS

Princeton University faculty members have been selected to lead the team of scientists responsible for a major NASA space observatory that will gauge the expansion of the cosmos and plumb the light of distant worlds.

The mission, called the Wide-Field Infrared Space Telescope (WFIRST) project, is scheduled to launch in about 10 years. The telescope will have two broad objectives: to study the nature of dark energy, a substance that scientists believe holds the key to understanding the expansion and, perhaps, the ultimate fate of the universe; and to directly observe and analyze light from planets orbiting distant stars as a way to understand their composition and atmosphere.

“WFIRST is designed to address science areas identified as top priorities by the astronomical community,” said Paul Hertz, director of NASA’s Astrophysics Division in Washington, D.C. “The Wide-Field Instrument will give the telescope the ability to capture a single image with the depth and quality of Hubble, but covering 100 times the area. The coronagraph will provide revolutionary science, capturing the faint but direct images of distant gaseous worlds and super-Earths.”

Two Princeton professors, N. Jeremy Kasdin '85 and David Spergel '82, are leading the teams of outside scientists and experts who are developing the mission. The two jointly hold responsibility for the scientific success of the project, with Kasdin focusing on the observation of exoplanets, and Spergel on the study of dark energy. Kasdin is a professor of mechanical and aerospace engineering and Spergel is the Charles A. Young Professor of Astronomy on the Class of 1897 Foundation.

NASA accelerated the project after the U.S. National Reconnaissance Office made available surplus telescopes that had originally been created for intelligence gathering. One of

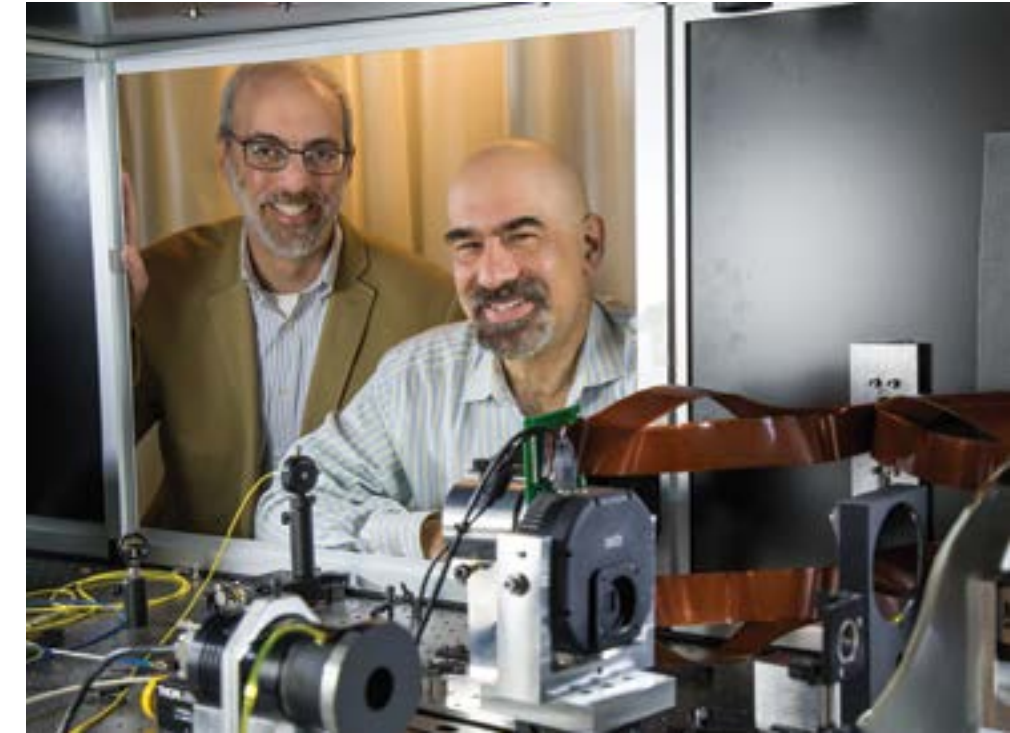


Photo by David Kelly Crow

the scopes – a large, powerful instrument that could survey a broad area of the sky – is being adapted to fulfill the WFIRST mission. Its 2.4-meter mirror (the same size as the Hubble Space Telescope) is being retrofitted to explore questions about dark energy and to examine light from distant planets.

With its coronagraph, WFIRST will be capable of observing planets several times the size of Earth. Kasdin said the long-term goal for projects like WFIRST is to achieve direct observation of Earth-like planets. “It will get us nearer to answering the question of whether we are alone in the universe,” he said. “It is one of the most important questions, scientifically and philosophically, that we have ever asked.” –**John Sullivan**

Princeton professors David Spergel, right, and N. Jeremy Kasdin, left, head a team of scientists designing a major NASA space observatory. The mission, WFIRST (Wide-Field Infrared Survey Telescope), will investigate the nature of dark energy and observe the light from planets orbiting distant stars.

'SCIENCE, SOCIETY, AND DINNER' SEMINAR BRIDGES FOOD, ENVIRONMENT, AND CULTURE

For decades, Craig Shelton has been one of the country's top chefs. But this spring, he took on an additional job: instructor at a Princeton freshman seminar.

After years in restaurants such as Le Bernardin, Bouley, and his own Ryland Inn, Shelton found himself shuttling between home-size electric ranges as he faced Princeton students and a barrage of questions. "Excuse me, chef, is this hot enough? Chef, what order do we cook these in? How do I slice this?"

Shelton was thrilled.

"You can't teach people about food only through books," he said after one class. "But to really understand food, and to understand the challenges of food and society, you can't just stay in the kitchen."

The course – "Science, Society and Dinner" – introduces students to the basics of knife skills, sautéing, and palate education, as

well as the water cycle, sustainable agriculture, and the biochemistry of taste – and how it all fits together.

"We are teaching people to understand the inputs of water and energy and carbon that go into creating their diets," said Kelly Caylor, an associate professor of civil and environmental engineering and director of the Program in Environmental Studies, who was the course's co-instructor. "When you make the choice between tomatoes from a local greenhouse or tomatoes from Mexico, what are the tradeoffs? What are the costs?"

As Shelton said, you can't learn about food without getting your hands dirty. So one night a week, the students sliced, fried, baked, and ate together. But before that, they listened as guest lecturers spoke about the science of food – the chemistry, social tradeoffs, and history. Field trips took them to local farms.

The course grew from a mix of student, community, and faculty initiatives. Karla Cook, of the Princeton Studies Food consortium, envisioned the course, and rising junior Rozalie Czesana, also of the consortium, proposed it as a seminar. Caylor signed on as the lead teacher and four other faculty members from the sciences, humanities, and public policy gave guest lectures. The course received support from the Office of the Dean of the College and the R. Gordon Douglas, Jr. '55 P86 and Sheila Mahoney S55 Fund.

"The course uses the community of the table to drive the science," said Cook, a longtime food journalist formerly of The New York Times, noting that issues such as climate change require bridging personal choices and scientific understanding. "If outrageously delicious food, with its art, its very human story, and its scientific requirements can move the needle and motivate students in their personal and professional lives, we're ready to cook." –JS

Photos by Karla Cook



In "Science, Society, and Dinner," first-year students studied the balance of food, economics, the environment, and culture in alternating sessions in the classroom and in the kitchen.

TIGHTLY SPACED OBJECTS COULD EXCHANGE MILLIONS OF TIMES MORE HEAT



Photo by Frank Wojciechowski

Alejandro Rodriguez (left), assistant professor of electrical engineering, found that microscopically close objects can radiate 1 million times more heat between each other than previously believed. Graduate student Prashanth Venkataram (right) uses related mathematics to extend the work to other types of energy transfer.

The sun's warmth crosses millions of miles of space to create a summer day; a campfire roasts marshmallows from several feet away. Scientists have understood the mathematics behind this ghostly heat transfer since the 19th century. But that math breaks down at very close quarters – within nano-scale electronics and solar-electricity cells where heat transfer is critical.

Researchers at Princeton and the Massachusetts Institute of Technology have developed a formula that describes the maximum heat transfer in such tight scenarios. Surprisingly – and encouragingly – the formula suggests that a million times more heat transfer is possible between close objects than previously thought.

"We now have a ceiling for how much heat transfer we can expect," said Alejandro Rodriguez, an assistant professor of electrical engineering at Princeton. "The fact that this ceiling is several orders of magnitude higher than has been previously demonstrated in existing material structures is extremely promising."

The formula is the first major amendment to the math that describes radiative heating – the Stefan-Boltzmann law – since it was established in 1879. With this new formula, engineers will know how to squeeze more out of their structural and material designs. Potential uses include converting heat into electricity, as well as cooling electronics such as processors.

Rodriguez's group at Princeton focuses on manipulating the interactions of light and matter at nanoscales. Typically, warm objects emit infrared light, which carries heat to other objects. At distances of less than the infrared wavelength, about eight microns, another type of radiation called evanescent waves takes over, Rodriguez explained. The new law accounts for the properties of evanescent waves.

"I am very optimistic that we will be able to come very close to reaching the limits both for near-field heat transfer and frequency conversion," said Rodriguez. "That's the spirit of much of the work I'm doing here at Princeton." –Adam Hadhazy

STUDENTS FIND CREATIVITY AT INTERSECTION OF ART AND ENGINEERING IN NEW COURSE

Photo by David Kelly Crow



From left, students Noah Fishman, Nora Bradley, and Sunny He designed a device that allows visually impaired people to experience color.

Inspired by the desire to help vision-impaired people experience color, three undergraduates created an arm-band device that allows its wearer to interpret color without the ability to see. The project emerged from a new class, “Transformations in Engineering and the Arts,” and lived up to the name of the course. In addition to transforming the sensation of color from a visual to a tactile experience, the students transformed an idea born on a whiteboard into a product that interweaves engineering concepts and artistic practices.

“Having a forum where our imagination is the limit has been an incredible experience,” said Nora Bradley, a sophomore in mechanical and aerospace engineering who worked with senior music major Noah Fishman and sophomore Sunny He of electrical engineering.

The team’s device uses a sensor to identify whatever color passes under it, then “displays” the hue by turning a rotary dial labeled in Braille.

A partnership between the Council on Science and Technology, the School of Engineering and Applied Science, the Department of Music, and the Lewis Center for the Arts, the class stemmed from several conversations among faculty and students interested in the intersection of arts and engineering.

“We were focused on leveraging a combination of the creative processes we use in engineering and the arts with ‘transformations’ as our framework,” said Naomi Ehrich Leonard ’85, who led the development of the course and is the Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering and director of the Council on Science and Technology. “For example, the students designed artful visualizations of sound and compositions that were translations of movement into sound,” she said. “It’s about working across disciplinary boundaries and not being confined to just one academic identification.”

The inaugural spring class was organized around four modules in the first half of the semester: visuals, sound, structure, and movement. These modules, led by faculty across the disciplines, included lectures, hands-on activities, discussions of aesthetics, mini design challenges, and tutorials on tools and resources available in a newly created teaching space called StudioLab. In the second half of the semester, students defined their own questions and created independent projects.

After junior Max Greenwald demonstrated his final project – a game that combined motion-tracking technology, theater lighting, and computer-game design – he said the best part of the class was the opportunity to play. “This project really energized me to be a maker and a doer and physically create something,” he said. “I couldn’t be more thankful to the class for allowing me to create something like this.” –**Catherine Shen**

FLUID SELF-ORGANIZES INTO STRUCTURE THAT CONTROLS CELL GROWTH AND HEALTH

Although known since the 1830s as a round, dark spot in a cell’s nucleus, only recently has the nucleolus gotten its full due. Scientists have learned that besides building a cell’s protein factories, this specialized subunit, or organelle, serves more broadly as a control center for cellular growth and health.

In the last several years amid a flurry of research, Princeton’s Clifford Brangwynne and colleagues discovered that the nucleolus behaves like a liquid with the consistency of honey. Yet somehow, this biological droplet maintains a complex, compartmentalized internal structure. Brangwynne, an assistant professor of chemical and biological engineering, and other researchers have puzzled over how such a liquid-like object could develop stably compartmentalized layers, rather than just fusing into a homogenous glob.

A new study by Brangwynne, his students, and their collaborators presents a solution to the paradox of nucleolar assembly and internal organization. Their paper, published online May 19 in the journal *Cell*, shows that the constituent proteins and RNA of nucleoli spontaneously assemble themselves into three distinct liquid layers thanks to their differing properties, such as surface tension and viscosity. Rather like how oil and water can coexist yet remain separate, the nucleolus develops liquid sub-compartments that enable its critical functions. These insights into the nucleolus’ form and function could ultimately point toward new ways to treat disease.

Photo by Frank Wojciechowski



“To get the characteristic layered, ‘core-shell’ architecture of the nucleolus, all you need to do is mix the right molecules together at sufficient concentrations,” said study co-lead author Marina Feric, a Ph.D. student in chemical and biological engineering.

“We’ve provided a biophysical mechanism for the structure of the nucleolus that automatically emerges from the collective behavior of immiscible liquids,” said the study’s other co-lead author, Nilesch Vaidya, a Helen Hay Whitney Postdoctoral Fellow in Brangwynne’s lab.

Brangwynne and colleagues had previously shown that a number of other organelles besides the nucleolus also are phase-separated liquid droplets of RNA and protein. The present findings point to how these organelles, all of which lack the obvious compartmentalization offered by membranes, can nevertheless exhibit intricate architectures tailored for their cellular duties.

“The basic properties of fluids dictate which components of the nucleolus are on the inside and the outside,” Brangwynne said. “Since the fundamental principles underlying this effect are observed even in non-living states of matter, we think this physical picture applies to many organelles inside cells.” –**AH**

Clifford Brangwynne’s research team at Princeton University has demonstrated that the nucleolus, an important cellular body, has a complex internal structure despite being made entirely of liquid. Far right: Brangwynne, an assistant professor of chemical and biological engineering, is shown with, from left, lab members Marina Feric and Lian Zhu, Ph.D. candidates, and Tiffany Richardson, Class of 2017.

‘EXTRAORDINARY PROCESSES’ COURSE LINKS ART AND ENGINEERING

Tension mounted at the Lewis Center for the Arts’ Lucas Gallery as Julia Wilcots, a civil and environmental engineering major, hung small sandbags from the graceful wood bridge that spanned the gallery’s clean white walls.

The bridge – thin strips of ash crossed in an X and mounted at their four ends – bowed and shimmied with each new weight. Its stresses and deflections seemed to transmit directly into the intently watching students gathered for the final session of “Extraordinary Processes,” a seminar offered jointly by the Program in Visual Arts and the Department of Civil and Environmental Engineering.

Having succeeded in meeting the course requirement of loading the bridge with 16 pounds, Wilcots and fellow student Neeta Patel tried radically shifting all the weight to one end, and Wilcots could not bring herself

to fully release her hand from the last weight as the asymmetrical structure danced near the edge of its stability.

“Go for it,” said Patel, a senior majoring in Program 2 studio arts in the Department of Art and Archaeology and Wilcots’ partner in making the bridge.

“I love it,” said Joe Scanlan, director of the Program in Visual Arts who co-taught the class this fall. “The artist is saying ‘Let go!’”

It was the sort of moment that Scanlan and his collaborator Sigrid Adriaenssens, associate professor of civil and environmental engineering, had hoped for as they invented a course to nudge students beyond their comfort zones at the boundary of art and engineering. The two chose to work with the wood of ash trees as a theme that was not grounded specifically in either art or engineering, but allowed an exploration of both.

During the semester, the students heard talks by experts on the emerald ash borer, an insect that is destroying ash trees, and visited the studios of legendary woodworker George Nakashima in New Hope, Pennsylvania. They built an apparatus to steam-bend wood and conducted labs that explored the difference between mathematical predictions and actual experience. They made self-portraits out of ash and culminated the semester with the bridge project.

“To work with one material so intensively for one semester is really enriching,” Adriaenssens said. Immersed in cutting, carving, bending, weaving, buckling, and simply handling the ash wood, the students’ creativity grew.

As the semester progressed, Scanlan said, arts students developed forceful ideas about measurement and utility, and engineers appreciated the aesthetic success possible even in a failed structural test.

“In the end there was not so much a split – here is an engineer and here is an artist,” Adriaenssens said. “The boundaries softened and the two had really merged.” **–SS**

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REVOLUTION LEADS TO BETTER DECISIONS, INNOVATIVE SOLUTIONS

by Jennifer Rexford '91

Society floats in a sea of data.

This magazine, the words printed in it, the photos displayed, all passed as ones and zeroes through the digital realm. The printing presses, the rolls of paper, the delivery trucks were created and managed with digital tools. But it does not stop there. These processes also left trails of data in their wakes, ripe for untold analysis. Modern society could no more run without data than without oxygen.

Data, the plural form of the Latin word meaning “given,” is obviously not a new concept for scientists. Factual observation has been the keystone of Western science since Francis Bacon opened his lab. But computation has altered science and engineering’s relation with data in ways as fundamental as Bacon’s original idea that science

should be founded on empirical observation rather than philosophy. By harnessing the power of modern computers and algorithms, researchers collect, store, and analyze data in entirely new ways – to amplify discovery and illuminate truths that were invisible before. New ways to extract meaning from data offer a promise of better decisions at all levels of science and society, and thus solutions to countless societal challenges.

In this issue of *EQuad News*, we see the vast scope of change that the data revolution has brought to science and engineering. Barbara Engelhardt is using computation to explore human genetic expression and its effect on the body’s systems (page 18); Clifford Brangwynne has combined computer modeling with lab work to bring new under-

Photo by Frank Wojciechowski



Neeta Patel, an art and archaeology major (left), and Julia Wilcots, a civil and environmental engineering major (right), hang weights from their bridge in the Lucas Gallery of the Lewis Center for the Arts as part of the class “Extraordinary Processes.”

DATA REVOLUTION LEADS TO BETTER DECISIONS, INNOVATIVE SOLUTIONS (continued from page 9)

standing to critical cellular functions (page 7); and two mechanical and aerospace engineers are developing methods to control unruly plasma particles as a step to harnessing fusion energy (page 20).

Han Liu's research team is developing new rules for big data analysis as a way to construct systems that find patterns as varied as genetic markers for autism and efficient trading for financial markets (page 14); Naomi Ehrlich Leonard's '85 work examines how many individuals with tiny data processing ability can form large groups to perform incredibly complex tasks (page 17); and Andrew Houck's '00 lab is seeking to change the nature of data and computation based on the strange rules of quantum physics (page 19).

We also see how much work remains to increase data's value as a tool and prevent abuse in how it is used. As computer programs increase in complexity, the group of Andrew Appel '81 is developing methods to root out software problems before they occur (page 16); Nick Feamster's team at the Center for Information Technology Policy is working to ensure that the internet remains an effective global platform for accessing and delivering data, without compromising our privacy or security in the process (page 15).

And, critically, we see how the data revolution is driving advances that benefit people around the globe. Warren Powell '77 is helping electric companies in Brazil integrate wind power into their grid (page 12); Eric Wood and Justin Sheffield are developing a flood warning system to prevent disasters in Chile

(page 11); and David Wentzlaff's team has developed an innovative tool to allow scientists around the world to develop new microchips without the need for expensive fabrication (page 14).

The Canadian philosopher Marshall McLuhan said that human society and actions are shaped by our tools of communication. Just as the internet and wireless technology have borne out McLuhan's observation countless times over, our ever-growing ability to collect and analyze diverse data, and uncover their meaning, will alter society in ways so profound we can hardly imagine them today. **E**



Photo by David Kelly Crow

Jennifer Rexford '91 is chair of the Department of Computer Science and the Gordon Y.S. Wu Professor in Engineering



Photo by VLADIMIR RODAS/AFP/Getty Images

FLOOD WARNING SYSTEM TO HELP EMERGENCY DECISIONS IN SOUTH AMERICA

by John Sullivan

In the summer of 2015, a freak cold front swept across the Andes and poured rain that triggered flash floods across parts of Peru and northern Chile. The floodwaters overflowed streambeds and sent mudslides roaring through rural communities. In the aftermath, the Chilean government estimated that more than 27,000 people were displaced.

The following spring, a team of Princeton researchers traveled to Chile to meet with scientists there and begin constructing a new flood warning system for the country. Led by Eric Wood, the Susan Dod Brown Professor of Civil and Environmental Engineering, and Research Scholar Justin Sheffield, the team hopes to help Chile plan for and respond to similar disasters in the future.

"The goal is to take our existing continental-scale model for Latin America and to increase spatial resolution to focus on Chile and provide the foundation for an operational system," said Wood, whose team previously developed hydrological monitoring systems for Africa, Latin America and the Caribbean, and the continental United States. "It will cover the entire country at a high spatial resolution, and our hope is that regular people can get direct access to the information."

Sheffield said the team plans to assemble an online system, including maps, that will

predict flooding seven to 14 days in advance. "It will be an operational forecasting system," he said.

The project is an outgrowth of work that Wood and Sheffield have done in recent years predicting drought in Africa. The researchers have developed sophisticated models that combine historic climate-station data, satellite information, and field reports to forecast droughts and estimate their severity.

"One of the challenges, and one of the most exciting things, is bringing together these very diverse sources of data," Sheffield said.

In Chile's case, the government has a sophisticated weather forecasting system as well as river and rain gauges that the Princeton team will work to integrate with satellite data. The team also will help develop a system to interpret data and pass them along to users. Wood and Sheffield said that it is critical for the system to present information reliably and understandably. For the system to be of value, citizens and community leaders must have access to information they need to cope with floods or droughts.

"We are doing the science, but we also have to bring the information to the people on the ground who are making the decisions," Sheffield said. **E**

Princeton researchers combined satellite data with data from government weather systems and river and rain gauges to predict flooding in South America and avoid the worst consequences of events such as the flooding shown here in Santiago, Chile, on April 27, 2015, which left 4 million people without water.

OPTIMIZATION EXPERT HELPS BRAZIL WITH ELECTRICITY- SUPPLY PROBLEMS

by John Sullivan

The historic drought that parched Brazil over the past two years was not just a water-supply problem – it was also a power problem.

The nation's heavy use of hydroelectricity, which had made it a model of renewable energy, contributed to rolling blackouts in some of Brazil's largest cities during severe droughts. Now, Princeton researchers are joining colleagues at a Brazilian university to help the operator of Brazil's electricity grid and the country's major utilities develop a system to better manage their electric system when hydropower dries up.

Warren Powell '77, a professor of operations research and financial engineering, and colleagues at the University of Campinas are analyzing plans for integrating new types of renewable energy into the Brazilian electricity grid. Powell, whose work focuses on optimization and uncertainty, has done extensive

research on electricity distribution systems. Among other topics, Powell has analyzed the PJM Interconnection – the massive grid that supports an area from the Mid-Atlantic states to the Ohio Valley. A group of 19 electric-power generation companies in Brazil asked for Powell's help in managing their own system, particularly how to integrate wind power into the grid.

"The Brazilians are the world's experts at modeling hydropower," Powell said. "But they need mechanisms to deal with the variability of wind power."

Managing an electricity grid is far more complex than turning on the power. The amount of power running through the system has to be carefully balanced to prevent shortfalls on one hand and wasted energy on the other. As the systems get larger, the job becomes more complicated. In the United States, grids are coordinated by federally regulated groups called Independent System Operators. The PJM Interconnection, for example, has over 61 million customers and coordinates roughly 1,300 power generators ranging from small solar fields to massive nuclear plants.

Matching power supply and demand requires that grid operators contend with fluctuations that occur seasonally, daily, and hourly. The balancing act becomes more challenging as grids integrate more renewable power sources, which can be more intermittent than traditional power plants.

A successful model, Powell said, will help operators create a system with enough options that extreme stress in one area, such as a drought, would not leave the grid crippled. To be effective, the system needs to reflect its environment as well as power demand.

"The Midwest has ethanol, Florida has solar, and the New England has hydropower from Quebec. We need to learn what Brazil has," he said. "We want to help Brazil develop a portfolio with enough options so there is always something to turn to." **E**



Photo by David Kelly Crow

Warren Powell, a professor of operations research and financial engineering who has done extensive research on electricity distribution systems, is helping Brazilian power companies smoothly integrate more wind power into their electric grid. Above, Powell talks with Nana Aboagye, a fourth-year Ph.D. student in operations research and financial engineering and member of his research group.

In Africa, where countries strive to expand agriculture to keep up with growing populations, data are a key element in mapping plans to provide food for billions.

Despite improvement in agriculture in many African countries, urban population across the continent has tripled over the past 30 years, leading to a net decrease in key food exports. The African Union estimates that 80 percent of farms in Africa are family-run operations of less than five acres.

This can make it extremely difficult for governments and regional organizations to plan for expansion and cope with demands for water and arable land. Kelly Caylor, associate professor of civil and environmental engineering, said that if political leaders don't have a good idea of the type of crops farmers are growing or the land they are using, policies could end up damaging agriculture in the long run.

"Improving the capacity to monitor the spatial distribution of agriculture, particularly among smallholder farmers, is critical to increasing agricultural productivity and food security," Caylor and other researchers wrote in a recent article in the journal *Remote Sensing of Environment*.

To address the problem, Caylor's team at Princeton has been working on several fronts. In the Mapping Africa project, researchers are asking internet users to help comb through satellite maps to identify different types of land use in certain regions. In other efforts, researchers are developing new techniques to identify land use by combining satellite imaging with other data.

Photos courtesy of Kelly Caylor



INTEGRATING CROP DATA AIDS FOOD SECURITY IN AFRICA

by John Sullivan



A sensor system developed at Princeton became the basis of a company, Arable, which allows farmers to collect critical data on crops. Adam Wolf (lower right) created the company with Ben Siegfried '12 (middle left) and Associate Professor Kelly Caylor, whose research assistants Ekomwa Akuwamand and Julia Signell (upper right) collected data in Kenya.



Photo by Frank Wojciechowski

Han Liu, assistant professor of operations research and financial engineering, is developing new mathematical tools that will allow other researchers to analyze complex scientific and business data with the weakest possible assumptions.

NEW MATH LETS DATA TAKE THE LEAD

“Big Data,” the use of powerful computation to find insights in massive fields of information, is in many ways a new science. As such, Han Liu said, it requires a new approach in mathematics.

“Things are starting to change and change fundamentally,” said Liu, an assistant professor of operations research and financial engineering.

For centuries, science has followed the same pattern: Scientists make conjectures, test them, and try to disprove their hypotheses. Big Data has changed that process.

“People are collecting large amounts of data. They analyze the data to find hidden patterns and use the patterns to lead to new hypotheses,” Liu said. “Many of these hypotheses are very counterintuitive and surprising.”

These new methods rely on statistics and probability and on advanced computing techniques in which the data “train” computers to interact with them so that future sets of data yield even greater results.

Scientists are already using this approach for many problems, from researching artificial intelligence to probing the genetic background of complex diseases and biological processes. The successful programs can find patterns that human intuition cannot see. But Liu said that most of the work is still very focused on applications.

In his Statistical Machine Learning Lab, Liu and his team are developing broad analytic tools that allow researchers to analyze complex scientific and business data with the weakest possible assumptions. In particular, they use data and computation as lenses to explore science and machine intelligence. “We need to build fundamental principles to make this a solid field,” Liu said.

Liu said that the current generation of students will play a critical role as Big Data develops as a science. “We are not trying to teach them techniques, but to be smarter, to be deep thinkers,” he said. –JS

TOOL EXPANDS ACCESS TO THE FIELD OF CHIP DESIGN

David Wentzloff devotes most of his research to designing new computers, but this year his team did something different: They developed a tool that allows others unprecedented ability to create their own sophisticated computer chips.

Wentzloff and his team created the system, called OpenPiton, after they realized there were almost no simple ways for chip designers – outside major corporations – to experiment with complex “manycore” systems, which have many processing units on the same chip.

“OpenPiton allows them to do all the research, from start to finish, using a single platform,” said Jonathan Balkind, a graduate student in Wentzloff’s team.

The project’s name comes from Wentzloff’s passion outside the laboratory: mountaineering. A piton is a spike driven into rock to

RESEARCHERS REVEAL ESCALATION IN CAT-AND-MOUSE GAME OF INTERNET CENSORSHIP

Researchers have found that the “Great Firewall” technology that controls internet traffic entering and leaving China is not merely an apparatus that statically blocks traffic. It also actively sends probes across the internet, preemptively searching for internet infrastructure and services that seek to circumvent its defenses.

“The Great Firewall is actively trying to find these sites so it can block them,” said Nick Feamster, a professor of computer science at Princeton and the acting director of the University’s Center for Information Technology Policy. “Active reconnaissance is the next step in the arms race,” he said.

In contrast to the decentralized management that characterizes much of the internet, China’s internet is tightly controlled: Traffic entering and leaving the country passes through infrastructure in just a few physical locations.

“It allows the Chinese government to see most traffic between China and the rest of the world,” said Roya Ensafi, a postdoctoral researcher who worked on the project.

To avoid this control, citizens often use online systems that encrypt communications and disguise sites visited. Princeton researchers have found that the government has responded to this with sophisticated efforts to identify and block these systems, leading to an online game of cat and mouse.

“It is an ongoing battle,” Ensafi said. –JS

Photo by Frank Wojciechowski



From left, Princeton researchers Roya Ensafi, a postdoctoral researcher in computer science, and Nick Feamster, a professor of computer science, are investigating methods that the Chinese government uses to control computer communications entering China from the rest of the world.

assist climbers on an ascent. The name OpenPiton reflects the team’s desire to offer tools that help others develop their ideas.

“We want to give people the tools they need to develop their own manycore processor designs,” said Wentzloff, assistant professor of electrical engineering. “OpenPiton is a first of its kind and by opening up our designs to people around the world we hope to spur huge innovation.”

In recent years, the performance of a single processor core has stopped increasing. So designers have increasingly begun using multicore and manycore systems that rely on spreading out computation across multiple separate processor cores.

“Instead of having faster cores, you have more of them,” said Mohammad Shahrads, another of Wentzloff’s graduate students.

another of Wentzloff’s graduate students.

Multicore and manycore systems require careful coordination among the cores to function properly, so their designs are often more complex than uni-processor systems. Wentzloff said until now there was no training program or reference design available for students or independent designers to build their own or experiment with multicore or manycore processors. His team tested OpenPiton by developing and fabricating a chip with 25 cores. The OpenPiton framework is available through the lab’s website (<http://parallel.princeton.edu/openpiton/>).

“Anyone, whether researcher or hobbyist, can use it,” Shahrads said. “It is completely open-source. That’s the goal of the project.” –JS

Photo courtesy of David Wentzloff



David Wentzloff, assistant professor of electrical engineering, led his team in creating an open-source tool that allows researchers to design sophisticated computer chips with far fewer resources than previously needed. Outside the lab, Wentzloff leads his team on mountaineering expeditions, which inspired the name of the chip-building tool, OpenPiton.

COMPUTER SCIENTISTS LAUNCH CAMPAIGN TO GUARANTEE BUG-FREE SOFTWARE

by Doug Hulette

Andrew Appel (center), professor of computer science, is leading a project called DeepSpec, which aims to eliminate bugs in complex software.

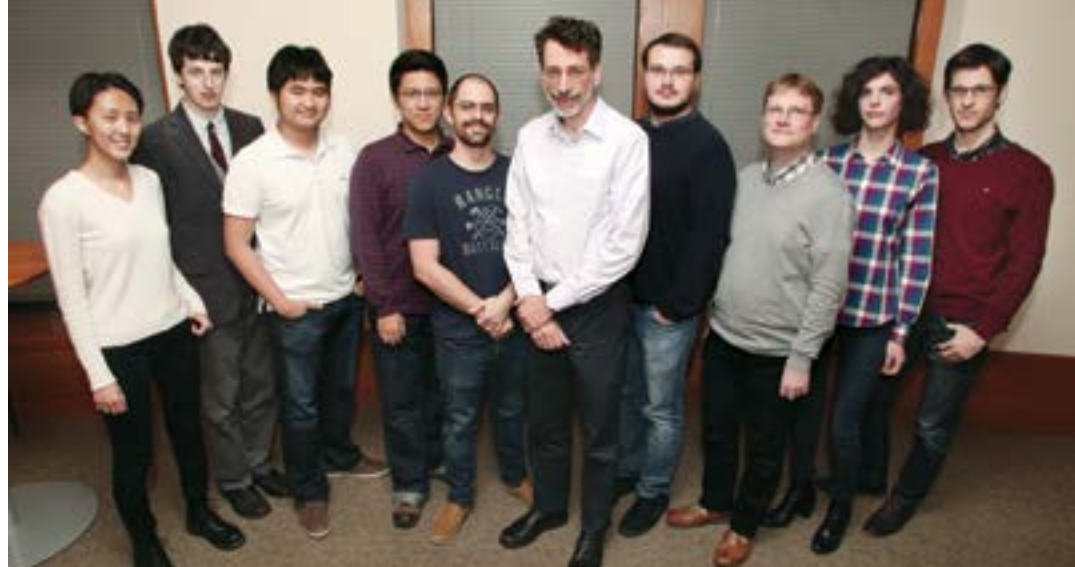


Photo by Frank Wojciechowski

The next time a software maker says to update your favorite computer application to fix defects or patch security holes, don't lose faith. Help is on the way.

A team led by Princeton computer scientist Andrew Appel '81 aims to exterminate software "bugs," the maddening programming errors that can open systems to hackers; disable cellphones, cars, and electronic devices; and cause errors in critical tasks such as tabulating election returns.

Funded by a \$10 million, five-year grant from the National Science Foundation, Appel and colleagues at the University of Pennsylvania, Yale University, and the Massachusetts Institute of Technology are developing integrated tools to eliminate uncertainty from the complex task of software development. A goal of the project, known as DeepSpec, is to reshape the industry by erasing the gap between researchers, who have made progress in the fight against bugs, and educators who are teaching the next generation of programmers.

"In our interconnected world, software bugs and security vulnerabilities pose enormous costs and risks," said Appel, the Eugene Higgins Professor of Computer Science. "When you press the accelerator pedal or the brake in a modern car, for instance, you're really just suggesting to some computer program that you want to speed up or slow down. The computer had better get it right."

The team's initial challenge is to dissect the overwhelming complexity of modern hardware and software to uncover factors that determine how computer components work together. The next step is to develop "deep specifications" – precise descriptions of software behavior – that will enable engineers to build and verify bug-free programs.

In a way, the project marks a shift in an industry in which many software writers work on isolated tasks and don't annotate their coding in ways to allow others to learn from their thinking. This weak institutional knowledge base has slowed progress toward a solution to the riddle of unintended consequences, especially in complex situations that involve multiple programs working at the same time, Appel said.

While the DeepSpec project is committed to promulgating its findings throughout the computer industry, a key will be changing what's taught in colleges and universities.

"Students in these courses will learn more, with less effort, because the DeepSpec approach allows us to clarify how the pieces fit together," Appel said. "I'm looking forward to test-driving this new curriculum at Princeton, to evaluate how much of a difference it makes." **E**

What does dance have to do with data?

Quite a lot, says Naomi Ehrich Leonard '85, the Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering.

Leonard studies the collective motion of groups such as dancers, starlings, or fish to better understand their decision making. Starling flocks, which swirl and twist like smoke, avoid predators and find food without direct communication between the birds. The group develops complex strategies and responds rapidly to external challenges.

"It's fascinating, and it seems to produce the type of collective behavior that we seek to create when we design distributed strategies for robotic systems that have to perform in complex environments," said Leonard. Examples of such complex environments include robotic exploration of the oceans or wide-scale environmental monitoring.

Leonard and her research team study how groups arrive at collective decisions and create models to evaluate various sets of rules that govern behavior. In the case of starling flocks, they found that consensus is most accurate and efficient when each starling adjusts its direction in response to observations of six or seven of its closest neighbors. Studying schools of fish, the group found that killifish exhibit coordinated oscillations in their motion and showed that this provides an advantage in how fast the fish come to a consensus.

"We combine the analysis of data with mathematical models to help us understand and predict behavior," Leonard said. "We can use the models to ask further questions and systematically gain a better understanding of mechanisms that explain what is observed and what is possible in design."

Dance also provides rich opportunities for studying and inspiring collective dynamics. Leonard recently collaborated on "There Might

Be Others," a dance work choreographed and directed by Rebecca Lazier, senior lecturer in the Program in Dance, with music composed by Dan Trueman '99, a professor of music.

In this work, which was performed in March at New York Live Arts in New York City, dancers make collaborative compositional choices in the moment.

Modeling and analysis not only help to understand collective decisions, they also provide insights into how to facilitate or influence the creative choices the artists make towards artistic goals.

"We explore the sensitivities of the group dynamics," Leonard said. "What makes it work? What makes it interesting? What makes it beautiful?" **E**

DATA YIELDS INSIGHT INTO BEAUTY AND POWER OF COLLECTIVE MOVEMENT

by John Sullivan



Photo by Paula Lobo

STATISTICAL TECHNIQUES ISOLATE ROLES OF GENES IN HUMAN TISSUES

by John Sullivan

Computer scientist Barbara Engelhardt (center) leads a research group that is deciphering gene-expression data, as well as data about other complex traits and disease.



Photo by Frank Wojciechowski

Trying to unravel the roles that a small set of genes plays in the regulation of a human trait is a daunting enough task, but when scientists try to apply the same analytic methods to a specific tissue or organ, they quickly run into a storm of information.

The functional role of any one gene is quickly obscured by a cascade of genes whose influence combines with that of other genes and environmental factors to affect multiple pathways. What starts as a few bits of information quickly becomes a blizzard of complex structured interactions.

“It’s really a needle in a haystack,” said Barbara Engelhardt, an assistant professor of computer science.

Engelhardt’s research group specializes in handling statistically difficult problems such as deciphering gene expression data, as well as data about other complex traits and disease. One of the great challenges of her work is finding subtle patterns among relatively small numbers of samples – even a large clinical trial might involve only a few thousand people, but tens of thousands of genes and millions of genetic mutations.

“Statistics in general has been developed for very large data sets – a billion Facebook

users, a trillion Google queries,” Engelhardt said. In most biological systems, on the other hand, “we don’t have an infinite amount of samples because of the cost to acquire each one.”

With relatively small pools of data, it can be difficult to separate biologically important patterns from random noise or technical effects. To address these problems, Engelhardt’s team harnesses the power of computation with innovative statistical methods. Identifying and characterizing these latent patterns can help scientists understand key mechanistic relationships in immense fields of data. Recent work has looked at the interactions of multiple genes in breast cancer, neuropsychiatric diseases and metabolic diseases.

“We are developing statistical methods to separate the structured noise from the signal,” she said. “We want to figure out the interactions driving disease from subtle patterns within the data.” **E**

Most scientists who work closely with data try to improve ways to process it or to harness it for other, broader inquiries.

Andrew Houck ’00 and his team are taking a different approach: they are trying to change the nature of data itself.

Houck, a professor of electrical engineering, and colleagues are seeking to build a quantum computer, a new type of machine that uses the strange rules of quantum mechanics to address problems that are not possible to solve with standard computers.

“Normally, when you think of a computer, you are thinking of a machine that stores information in binary, a series of zeroes and ones,” Houck said. “A quantum computer is one that processes an entirely new kind of information. It is not restricted to ones and zeros – because of the laws of quantum mechanics, it can be both zero and one at the same time.”

In a quantum computer, each of the quantum bits, or qubits, remains in this uncertain state until their value is measured by the computer, at which point they switch to become either a zero or a one. This unusual behavior allows mathematicians to write unique programs that predict the probability of a qubit assuming a value and to build that probability into a final result.

“The magic is when you measure this thing it forces your answer to become a discrete outcome,” Houck said. The math is complex but, as Houck noted, “if you run the algorithm just right, you can answer certain questions really efficiently, and these questions are very difficult to handle on classical computers.”

Possible uses include powerful code-breaking systems or solutions to key biological questions such as how proteins acquire their three-dimensional shapes.

An illustration by researchers in the lab of Andrew Houck depicts a new technique to measure photons – particles of light – in a superconducting quantum simulator, a form of quantum computing.

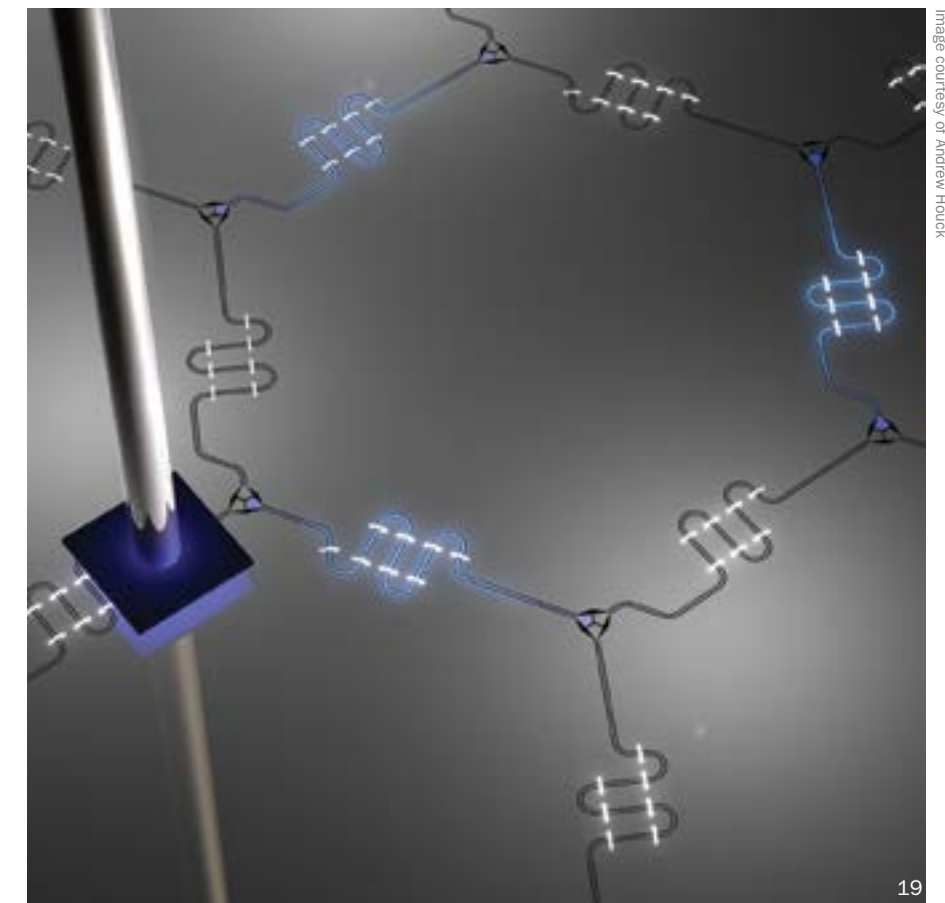


Image courtesy of Andrew Houck

BEYOND ONES AND ZEROES: QUANTUM DATA PROMISE NEW REALM OF PROBLEM-SOLVING

by John Sullivan

DATA DRIVE QUEST TO CONTROL NUCLEAR FUSION

by John Sullivan



Photo by Frank Wojciechowski

Egemen Kolemen (left), assistant professor of mechanical and aerospace engineering, speaks with Al von Halle, head of engineering and operations for NSTX-U, a major experiment in nuclear fusion being conducted at the Princeton Plasma Physics Laboratory.

Running a fusion reactor is like holding part of the sun in a bottle – its heart is a raging storm of particles trapped in a magnetic field.

To translate this storm's power into a practical energy source, scientists will have to harness and control the reactor by adjusting the twists and flows of its superheated particles.

"Plasma can destabilize in milliseconds," said Egemen Kolemen '08, an assistant professor in mechanical and aerospace engineering and the Andlinger Center for Energy and the Environment. "To control the reaction, we need to react in the same timescale."

Kolemen is one of several Princeton engineers working with colleagues at the Princeton Plasma Physics Laboratory (PPPL), a U.S. Department of Energy lab administered by Princeton University, to solve critical problems in making fusion energy a practical reality. In particular, Kolemen and Clarence Rowley '95, a professor of mechanical and aerospace engineering, lead separate projects to control the behavior of a state of matter known as plasma.

Instant decisions

A fusion reactor starts by heating light atoms such as hydrogen gas far beyond the temper-

ature of the sun. At such temperatures, electrons fly free of their atoms, leaving a swirl of electrically charged particles called plasma. If engineers can arrange this plasma into just the proper configuration, the particles will slam into each other and fuse into new types of matter, releasing massive amounts of energy. Scientists have been able to do this for minutes at a time, but maintaining a stable reaction for a fusion power plant that needs months to years of operation is a different story. The plasma constantly seeks to fling itself apart. Even if operators prevent this, they still have to control the plasma's constant twists and swirls to maximize the collisions among particles.

To make things more complex, there is no easy way to take real-time measurements of plasma's configuration – observations are possible, but they take time to analyze. That is where Kolemen's work begins.

"We gather pieces of diagnostic measurements and quantify the uncertainty," he said. "We try to put all this information in physics models and figure out what the situation is in the reactor."

Kolemen is assembling algorithms that will evaluate measurements of the plasma and make rapid calculations that trigger minute shifts in the reactor. The goal is to create an automated system that reacts quickly enough to maintain stability within the plasma.

"You need to understand all of the diagnostics, analyze them with the physics, predict if there is going to be a disruption, and take action," he said.

It might sound impossible, but Kolemen said the framework of the system is in place. He said engineers are now working to build up the system and increase its reliability.

"Making something so it works once in a while is easy," he said. "Going from a system that is functional for 90 percent of the time to the more than 99.99 percent reliability needed for a fusion power plant – that requires a bit more thinking."

Finding flow

While Kolemen seeks tools to control plasmas as they change, Rowley is developing mathematical models that reveal why instabilities develop in the first place.

To an untrained eye, the plasma seems to twist and roll randomly, but Rowley said that underlying patterns often hide in a multitude of details.

"If you really want to understand what is going on, to get to the heart of the matter, you want to strip away those details," Rowley said. "Often, it's something simple."

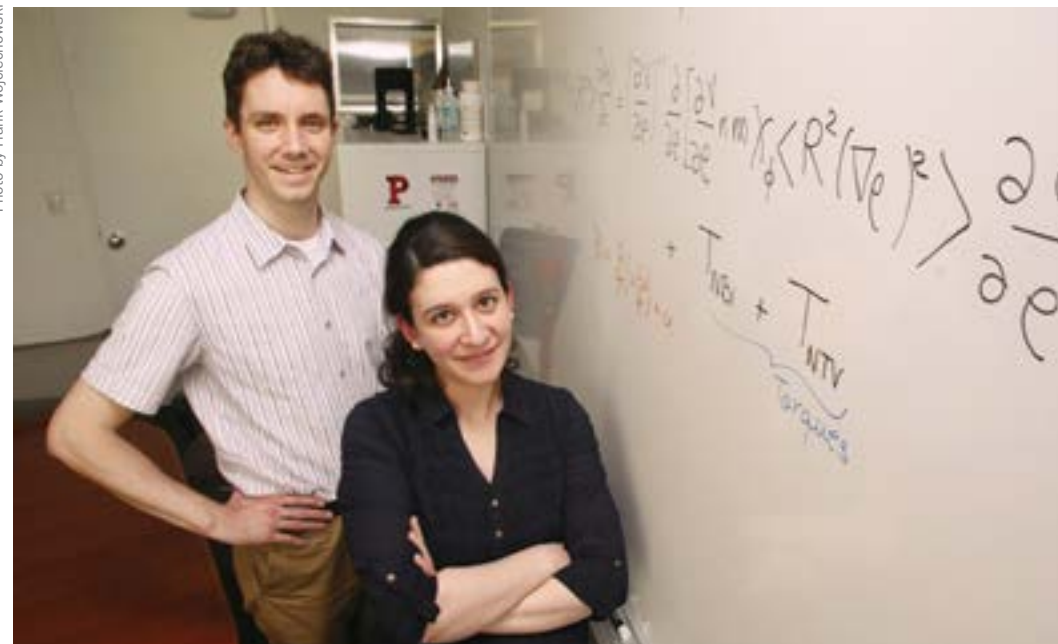
Imène Goumiri, a graduate student in Rowley's lab, recently worked with colleagues at Princeton and PPPL to develop a system using mathematical modeling and high-speed controls to reduce turbulence in plasmas created in the lab. Built on data from previous experiments, the program reacts quickly to changes in the plasma's flow and reduces instabilities by rotating sections of the plasma at different speeds.

Rowley's team has revealed how small changes that occur at critical locations and are amplified by other factors. The amplification can eventually cause the small change to play a big role in the overall flow.

"Trying to identify the features of the flow that are very sensitive to change is a big part of this business," Rowley said. "Even though this is about fluid dynamics or plasma, it can apply to any domain, which is why it is useful to think about it in a mathematical framework."

"For instance, if you are trying to understand instabilities in a power grid that could lead to blackouts, you want to know if there are places in the grid that are really vulnerable – if one generator went off, it could send ripples through the grid. These same techniques could give you a better understanding of that as well." **E**

Photo by Frank Wojciechowski



Clarence Rowley (left) and graduate student Imène Goumiri built on data from previous experiments in nuclear fusion to develop a method to reduce turbulence in the chaotic swarm of ultra-hot particles known as plasma, which is necessary for producing fusion power.

Photo by Noel Valero '82 *85



University President Christopher L. Eisgruber (left) awarded Presidential Teaching Awards to Professors Celeste Nelson (middle) and Brian Kernighan (right) at Commencement May 31.

Photo by Denise Applegate



Mung Chiang

'LIKE LEARNING PHYSICS FROM EINSTEIN' – STUDENTS LAUD TEACHERS

Five engineering professors were recognized for distinguished teaching at the 2016 graduation ceremonies.

Michael Celia *83, the Theodora Shelton Pitney Professor of Environmental Studies and professor of civil and environmental engineering, received the Graduate Mentoring Award. The director of the Program in Environmental Engineering and Water Resources, his research focuses on subsurface hydrology and energy systems, including carbon dioxide sequestration and shale gas. Students praised Celia's dedication. One student said that Celia "truly embodies what it means to be a mentor" and "will sit with you for no matter how long to go over problems and work them through with you step-by-step until you can explain it back to him."

Mung Chiang, the Arthur LeGrand Doty Professor of Electrical Engineering and director of the Keller Center, received the engineering school's Distinguished Teaching Award. His research uses mathematical analysis to strengthen and improve the design of wireless networks. In announcing the award, Yueh-Lin (Lynn) Loo *01, the engineering school's acting vice dean, noted that Chiang is known for his dedication to the craft of teaching. His undergraduate networking course is informally known as the "20 questions" class for the way he poses and helps students answer underlying questions about networks of various kinds. An online version of the course, "Networks: Friends, Money, and Bytes," has drawn more than 100,000 students since fall 2012.

Pablo Debenedetti, the Class of 1950 Professor in Engineering and Applied Science, received the Phi Beta Kappa teaching award. Debenedetti also serves as the University's dean for research. Seniors Kevin Silmore and Elizabeth Banes paid tribute to him as "a truly exceptional and inspiring teacher here at Princeton." Banes wrote in the citation for the

award, "Dean Debenedetti has made a name for himself as the kind, yet challenging lecturer of 'Introduction to Thermodynamics,' a pre-requisite course for all chemical and biological engineering majors." Banes also valued Debenedetti's qualities as a mentor to generations of Princeton students. "On weekdays, Dean Debenedetti will often be found holding personal office hours into the late evening, guiding any student in need of help through the complex web of thermodynamical concepts."

Brian Kernighan *69, a professor of computer science, received the Presidential Teaching Award. Kernighan is known for his ability to explain complex subjects. One colleague described the breadth of Kernighan's support of students: "Professor Brian Kernighan has distinguished himself as a master educator through his classroom teaching, his independent work-advising, his academic advising, his mentoring, and his outreach to the community of Princeton students. A legend in the computing field long before his arrival at Princeton, Brian leaves an indelible mark on every student he advises, teaches, and mentors." One undergraduate said "learning how to program from Brian Kernighan is like learning physics from Albert Einstein or calculus from Isaac Newton."

Celeste Nelson, a professor of chemical and biological engineering and director of the Program in Engineering Biology, received the Presidential Teaching Award. Colleagues underscored Nelson's talent in teaching and developing classes, including "Quantitative Physiology and Tissue Design" and "Physical Basis of Human Disease." A colleague noted that Nelson's ability to make connections across disciplines was demonstrated by the molecular biology department's invitation for her to teach its "Quantitative Principles in Cell and Molecular Biology" course. One recent graduate said, "We thrived under her expert and thoughtful teaching."

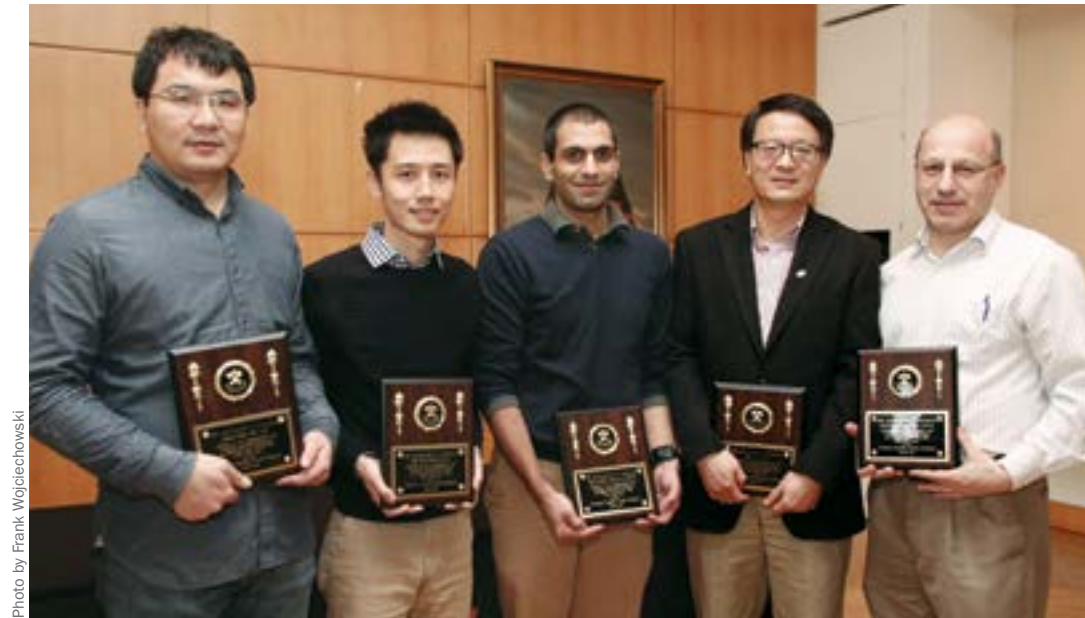


Photo by Frank Wojciechowski

CARTER AND CELIA ELECTED TO NATIONAL ACADEMY OF ENGINEERING

Two members of the engineering faculty, **Emily Carter** and **Michael Celia** *83, have been elected to the National Academy of Engineering, one of the highest professional honors for American engineers.

Carter, the dean of engineering and the Gerhard R. Andlinger Professor in Energy and the Environment, was recognized by the academy for "the development of quantum-chemistry computational methods for the design of molecules and materials for sustainable energy."

The founding director of the University's Andlinger Center for Energy and the Environment, Carter is known for her pioneering work in theoretical and computational chemistry. Among many professional honors, in 2008 Carter was elected to the National Academy of Sciences and the American Academy of Arts and Sciences. She also holds an appointment as professor of mechanical and aerospace engineering and applied and computational mathematics.

Celia, the Theodora Shelton Pitney Professor of Environmental Studies, was honored by the academy for "contributions to the development of subsurface flow and transport models in groundwater remediation and CO₂ sequestration."

His research focuses on modeling fluid flows in the subsurface with applications to groundwater flow, groundwater contamination, and subsurface energy systems, including studies of fluid migration in shale-gas systems. A fellow of the American Geophysical Union and the American Association for the Advancement of Science, Celia is the recipient of the 2005 AGU Hydrologic Sciences Award, and the 2014 Honorary Lifetime Membership Award from the International Society for Porous Media.

STUDENTS LAUD FACULTY FOR EXCELLENCE IN TEACHING

The undergraduate Engineering Council and the Graduate Engineering Council annually elect professors to receive the groups' Excellence in Teaching Award. The recipients at the spring 2016 ceremony were, from left, Han Liu, Hansheng Diao, Naveen Verma, Nan Yao, and Howard Stone.



Emily Carter

Photo by David Kelly Crow



Michael Celia

Photo by Frank Wojciechowski

RECENT FACULTY AWARDS AND HONORS

CHEMICAL AND BIOLOGICAL
ENGINEERING**José Avalos**

Research Fellowship, Alfred P.
Sloan Foundation

Clifford Brangwynne

ASCB-Gibco Emerging Leader
Prize, American Society for
Cell Biology

Pablo Debenedetti

Fellow, American Physical
Society

Yannis Kevrekidis

W.T. and Idalia Reid Prize,
Society for Industrial and
Applied Mathematics
Corresponding Member,
Academy of Athens
Einstein Visiting Fellow, Einstein
Foundation, Berlin
Rothschild Visiting Distinguished
Fellow, University of
Cambridge

Yueh-Lin (Lynn) Loo *01

Finalist, Blavatnik National
Award for Young Scientists
IDEAS Lab Moderator, World
Economic Forum Annual
Meeting of the New
Champions

Celeste Nelson

College of Fellows, American
Institute for Medical and
Biological Engineering

CIVIL AND ENVIRONMENTAL
ENGINEERING**Maria Garlock**

T.R. Higgins Lectureship Award,
American Institute of
Steel Construction

Ning Lin *10

Howard B. Wentz Jr. Junior
Faculty Award

Catherine Peters

Fellow, Association of
Environmental Engineering
and Science Professors

Claire White

CAREER Award, National Science
Foundation

Eric Wood

Highly Cited Researcher,
Thomson Reuters

COMPUTER SCIENCE

Mark Braverman

Presburger Award, European
Association for Theoretical
Computer Science

Barbara Engelhardt

Research Fellowship, Alfred P.
Sloan Foundation
E. Lawrence Keyes Jr./Emerson
Electric Co. Faculty
Advancement Award

Jennifer Rexford '91

Athena Lecturer, Association for
Computing Machinery,
Council on Women in
Computing
Best Paper Award, Association
for Computing Machinery,
Symposium on SDN
Research

Robert Tarjan

Honorary Doctor of Mathe-
matics, University of
Waterloo

David Walker

Best Paper Award, Association
for Computing Machinery,
Symposium on SDN
Research
Robin Milner Young Researcher
Award, Association of
Computing Machinery,
Special Interest Group on
Programming Languages

ELECTRICAL ENGINEERING

Emmanuel Abbe

CAREER Award, National Science
Foundation
Google Faculty Research Award

Stephen Chou

Nanoimprint Pioneer Award,
14th International Con-
ference on Nanoimprint and
Nanoprint Technology

Claire Gmachl

Walter Curtis Johnson Prize for
Teaching Excellence

Antoine Kahn *78

Fellow, School of Engineering,
University of Tokyo

Prateek Mittal

CAREER Award, National Science
Foundation
Cisco Faculty Research Award
Google Faculty Research Award

H. Vincent Poor *77

Fellow, World Academy of
Sciences
Fellow, National Academy of
Inventors
Fritz Medal, American Asso-
ciation of Engineering
Societies
Highly Cited Researcher,
Thomson Reuters

Barry Rand *07

Young Faculty Award, DARPA
Young Investigator Award, Office
of Naval Research

Alejandro Rodriguez

E. Lawrence Keyes Jr./Emerson
Electric Co. Faculty Advance-
ment Award

Sergio Verdu

Award for Scientific Reviewing,
National Academy of
Sciences



Jennifer Rexford

Sigurd Wagner

IBM Faculty Award

Gerard Wysocki

Best Paper Award, Japanese
Symposium on Combustion

MECHANICAL AND
AEROSPACE ENGINEERING**Emily Carter**

Fred Kavli Innovations in
Chemistry Lecturer, American
Chemical Society

Marcus Hultmark *11

Young Investigator Award,
U.S. Air Force

Yiguang Ju

Best Paper Award, Japanese
Symposium on Combustion

Egemen Kolemen *08

Torkil Jensen Award, General
Atomics/U.S. Department of
Energy

Chung K. (Ed) Law

Highly Cited Researcher,
Thomson Reuters

Naomi Ehrich Leonard '85

Innovation Hall of Fame,
A. James Clark School of
Engineering, University of
Maryland

Michael Muller

Alfred Rheinstein Faculty Award

Photos by Frank Wojciechowski
unless otherwise indicated

OPERATIONS RESEARCH AND
FINANCIAL ENGINEERING**Amir Ali Ahmadi**

CAREER Award, National Science
Foundation

Best SICON Paper Prize, Society
for Industrial and Applied
Mathematics

Google Faculty Research Award
U.S. Junior Oberwolfach Fellow,
National Science Foundation
Howard B. Wentz Jr. Junior
Faculty Award

Han Liu

Tweedie New Researcher
Award, Institute of
Mathematical Statistics



Emmanuel Abbe



Egemen Kolemen

ARNOLD LEADS
MATERIALS INSTITUTE

Craig Arnold, professor of mechanical and aerospace engineering, was appointed director of the Princeton Institute for the Science and Technology of Materials (PRISM) as of January 1. He had served as interim director since July 2015 when James Sturm, the Stephen R. Forrest Professor of Electrical Engineering, stepped down after 18 years leading the institute and earlier materials-science initiatives.

Arnold's research ranges from funda-
mental science to applied technology with a focus on materials synthesis and processing. He has particular interests in energy storage systems, laser materials processing, and advanced optics. Arnold co-founded TAG Optics, a company that uses technology developed in Arnold's lab for ultra-fast focusing lenses.

LOO TAKES HELM
AT ANDLINGER CENTER**Yueh-Lin (Lynn)**

Loo *01, the Theodora D. '78 and William H. Walton III '74 Professor in Engineering and professor of chemical and biological engineering became director of the Andlinger Center of Energy and the Environment on July 1. She succeeded Founding Director Emily Carter, who is now dean of engineering.

A leader in organic and plastic electronics, Loo researches the development and processing of materials for low-cost, lightweight, and flexible solar cells and circuits. In recent work, Loo's group developed transparent solar cells to power technology that changes a material's color in response to electrical signals. Such "smart" windows will decrease energy use associated with the heating, cooling, and lighting needs of buildings.



José Avalos



Claire White



Maria Garlock



Stephen Chou

Photos by Frank Wojciechowski
unless otherwise indicated

PARTNERSHIPS YIELD GLOBAL IMPACT FOR ENGINEERS WITHOUT BORDERS

When Josh Umansky-Castro joined Engineers Without Borders (EWB) as a freshman, he traveled to the remote mountain town of La Pitajaya, Peru, to help build and maintain two water distribution systems serving 21 families.

The pipe systems that carry water downhill from a distant spring were designed by Princetonians who came before him, and who left a lasting impact on the mountain community.

Now a rising senior in mechanical and aerospace engineering, Umansky-Castro is making his own mark.

As one of two project managers for a new project in Pusunchás, Peru, his team is building a water system that will serve 120 families and provide over 6,300 gallons of running water per day. Each household is expected to have its own tap, a goal that local

Photo by Josh Umansky-Castro



The Princeton University chapter of the service group Engineers Without Borders received national recognition for its effectiveness in executing an expanding set of projects to provide clean water to communities in Africa and South and Central America. Above, students joined with community members in the summer of 2014 to dig a trench near La Pitajaya, Peru.

residents have strived for in the last 20 years.

“People have called us crazy,” Umansky-Castro said. “It’s going to be a lot of trenching.”

It’s the sort of dedication that has earned national recognition for the Princeton chapter. Among nearly 300 Engineers Without Borders programs in the United States, Princeton’s was honored at the EWB-USA International Summit in Denver this year with the organization’s Premier National Chapter Award. The Princeton team also received the Premier Chapter Award for the Northeast earlier this year.

The award recognizes a range of initiatives. In addition to the Peruvian pipeline, Princeton’s EWB program is designing and building rainwater catchment systems – which transfer rainwater from a building’s roof into a water tank through pipes – in the Dominican Republic and in Kenya.

“It’s pretty incredible when you think of the scale of EWB nationwide,” said Lucy Tang, a mechanical and aerospace engineering major and co-president of Princeton EWB. “The actual outcomes of the projects have been palpable for local people. Our students go out and do tough work.”

Tang’s co-president, Brendan Hung, an operations research and financial engineering major, said that the Princeton chapter develops strong relationships with the communities they serve, focusing on sustainability and regional needs.

“We are a successful chapter in balancing multiple programs, and we make sure to develop meaningful projects,” Hung said.

Umansky-Castro acknowledged that the new project in Pusunchás presents challenges on a larger scale than ever before, but said he is confident that the knowledge passed on from former EWB generations will help his team come through.

“EWB has redefined my perception of what college students are capable of,” Umansky-Castro said. –**Anna Windemuth ’17**

CLASS DAY AWARDS HONOR RESEARCH CONTRIBUTIONS AND SERVICE

The Princeton Class of 2016 included a record number of engineering students: One quarter of the class, or 317 students, earned BSE degrees, 37 percent of whom were women. Their plans for next year include graduate school at universities such as Massachusetts Institute of Technology, Harvard, and Oxford; government service; professional sports, including the National Football League; working at companies such as Merck, Microsoft, Google, Facebook, and some of the students’ own startups; and military service. At Class Day ceremonies May 30, the School of Engineering and Applied Science presented the following awards:

J. Rich Steers Award

Stephen O’Neill

Chemical and Biological Engineering

Eric Principato

Mechanical and Aerospace Engineering

Jeffrey O. Kephart ’80 Prize

Aditya Trivedi

Physics

Tau Beta Pi Prize

James Evans

Computer Science

Xiaoyan Han

Operations Research and Financial Engineering

Joseph Clifton Elgin Prize

Pelin Asa

Civil and Environmental Engineering

Stacey Huang

Electrical Engineering

George J. Mueller Award

Isaiah Brown

Operations Research and Financial Engineering

Calvin Dodd MacCracken Senior Thesis/Project Award

Sarah Cen

Mechanical and Aerospace Engineering

Zachary Schiffer

Chemical and Biological Engineering



Outgoing dean of engineering H. Vincent Poor (right) awarded prizes for scholarship and service at Class Day ceremonies May 30. Top row: Stephen O’Neill, Zachary Schiffer, Eric Pincipato, Riley Fitzgerald, Isaiah Brown. Middle row: Xiaoyan Han, Matthew Matl, Aditya Trivedi, James Evans, Matthew Volpe, Sarah Cen. Front row: Jason Altschuler, Stacey Huang, Pelin Asa.

Lore Von Jaskowsky

Memorial Prize

Riley Fitzgerald

Mechanical and Aerospace Engineering

Matthew Volpe

Chemical and Biological Engineering

James Hayes-Edgar Palmer

Prize in Engineering

Jason Altschuler

Computer Science

Matthew Matl

Electrical Engineering

Photo by Noel Valero '82 *85

Photos by David Kelly Crow



In a collaboration between electrical and civil engineers, students designed a flexible sensing sheet to warn engineers of weakness in bridges and other structures.

SENIOR THESIS LEADS TO CONCRETE RESULTS

When two Princeton engineering students set their minds to solving a tough technical problem for their senior theses this year, the results were concrete – or at least applicable to concrete.

“The objective was to develop a sensor sheet to detect strains over large areas of structures,” said Matthew Gerber '16. He said the ultimate goal was to protect structures such as skyscrapers and dams by detecting “cracking, yielding, warping, anything significant beyond everyday normal use.”

James Sturm '79, an electrical engineering professor who was one of the students' advisers, said engineers have been pursuing a large-area sensor to monitor strain on the surfaces of buildings, bridges, and airplane wings for years. But so far the best sensors measure along a one-dimensional line rather than a two-dimensional surface.

“We sought a sheet of sensors to cover the surface,” said Sturm, the Stephen R.

Forrest Professor of Electrical Engineering. “We did some fundamental work on an approach several years ago, but had had little progress translating the electrical engineering end of it into a practical way forward.”

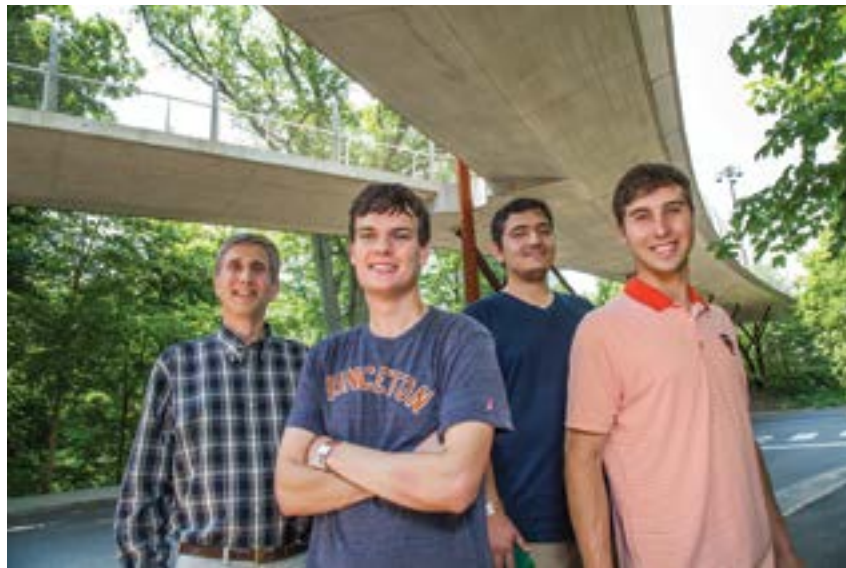
Campbell Weaver '16 had been looking for a thesis idea with a practical impact, so Sturm suggested he explore ways to revive the wide-area sensor problem. Weaver quickly focused on two concerns: The electronics within the sensing sheets seemed overly complicated, and there was no reliable way to attach the sheet to a surface.

The project grew to include a multidisciplinary team: In addition to Sturm, Branko Glišić, an associate professor of civil and environmental engineering, had already been working on a similar sensing problem. Gerber, one of Glišić's students, joined with Weaver to work on the adhesive problem. Other electrical engineering colleagues with expertise in sensors and flexible electronics joined as advisers: Associate Professor Naveen Verma, Professor Emeritus Sigurd Wagner, and post-doctoral researcher Levent Aygun.

Weaver devised a method to split the electronics into two units: the bare minimum needed in the sensing sheet and all the rest on a separate rigid circuit board. Meanwhile Gerber's extensive tests of adhesives led to a particular product that was strong yet flexible.

Weaver and Gerber ultimately developed a system that they successfully deployed on the University's Streicker Bridge. Aygun, who is continuing the research and did some of the early work along with a summer intern Juan Manuel, said recent results from the system have been very successful.

“What came out in the end is something we have sought for about four years,” Sturm said. “The work is of both fundamental and practical importance.” —JS



From left, Professor James Sturm, Campbell Weaver, Levent Aygun, and Matthew Gerber teamed up to develop the new sensor.



Photo by Frank Wojciechowski

Graduate students (from left) Nana Kobby Aboagye, Akil Word-Daniels, Kevin Sallah, and Naima Hammoud received Excellence in Teaching Awards from the University's Engineering Council and Graduate Engineering Council, which are the undergraduate and graduate student organizations of the School of Engineering and Applied Science.

GRADUATE STUDENTS CELEBRATED FOR EXCELLENCE IN TEACHING

The Princeton University Graduate School presented two graduate students in engineering with its annual Teaching Awards in recognition of their outstanding abilities as teachers. **Georgina Hall** from the Department of Operations Research and Financial Engineering and **Akil Word-Daniels** from the Department of Electrical Engineering were among this year's nine recipients campus-wide.

Hall, a fourth-year graduate student, served as a teaching assistant for “Computing and Optimization for the Physical and Social Sciences,” “Convex and Conic Optimization,” and “Probability and Stochastic Systems,” which had more than 200 students. In one semester, she eagerly helped teach two courses at once. Assistant Professor Amir Ali Ahamdi, who co-taught with Hall for four semesters, wrote: “She simply shined in both courses. And she won a teaching award from the Engineering Council for her performance in ORF 309.” Professor Emeritus Erhan Çinlar added: “Georgina was one of the great teaching assistants. Her precepts were well

attended, her grading was impeccable, and she was appreciated by the students for her ability to explain difficult matters of logic and analysis. Ever since, she was every faculty member's first choice for a teaching assistant.”

Word-Daniels, a third-year graduate student, served as a teaching assistant for “Electronic and Photonic Devices.” In her nomination, Claire Gmachl, the Eugene Higgins Professor of Electrical Engineering, described Word-Daniel's efforts: “It was Akil who proposed and took upon himself to rework the Silicon Lab ... to give all students the very best lab experience. Akil designed a new lab project, taught it to his fellow A.I.s [teaching assistants], and guided 50 students through it; he did so on his own account and at significant extra workload for himself.” Gmachl continued: “Akil made a real, positive, and lasting difference for the students in ELE 208.” One student commented, “Best Lab TA ever.” And another added, “He was engaging and funny, but also dedicated to making sure everyone understood what was going on.” —JS

Photo by Sameer Khan/Fotobuddy



Georgina Hall

Photo by Sameer Khan/Fotobuddy



Akil Word-Daniels

GRADUATE RESEARCH SPANS FUNDAMENTAL DISCOVERY AND PRACTICAL SOLUTIONS

Graduates students at Princeton Engineering work at the intersection of fundamental science and practical, creative solutions. Here are just a few examples of students delving deep into chemical, physical, technological, and mathematical problems – all with an aim to addressing societal needs such as food security, health, environmental protection, and robust computer and financial systems.



WILL MULHEARN

CHEMICAL AND BIOLOGICAL ENGINEERING

Hometown:

West Chester, Pennsylvania

Research:

Mulhearn is working to improve the resilience of polyethylene plastic under stress. On its own, polyethylene has desirable toughness because it partially crystallizes at room temperature. (This is why polyethylene milk bottles look cloudy.) Mulhearn seeks to dramatically improve the resistance of items made of polyethylene to deformation by the introduction of a second, highly inflexible polymer that can act as a support for the crystal domains. These hybrid materials are called block copolymers, in which a long, chain-like molecule of polyethylene is bonded to a second chain of a chemically different polymer.

Recent honor:

First place in the Journal of Polymer Science poster competition.



STEPHANIE DEBATS

CIVIL AND ENVIRONMENTAL ENGINEERING

Hometown:

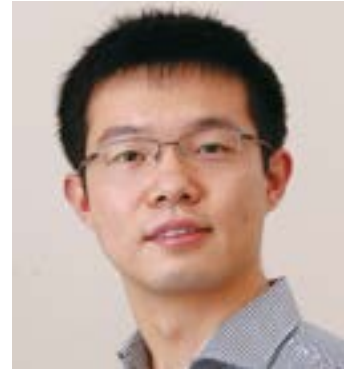
Irvine, California

Research:

Debats develops computer vision and machine-learning algorithms to analyze satellite imagery and detect the types of plants that cover the Earth's surface. She focuses on identifying subsistence agriculture in Sub-Saharan Africa, a region that typically has few sources of data for analyzing agricultural practices. By efficiently extracting vast feature sets for millions of image pixels, she trains computer algorithms to accurately identify the subtle patterns that define subsistence agriculture. The resulting data can be used to improve models that predict food insecurity hotspots, as well as track land-cover changes in the developing world.

Recent honors:

NASA Student Research Initiative Grant; Mary and Randall Hack '69 Graduate Award in support of innovative research on water and water-related topics.



XIN JIN

COMPUTER SCIENCE

Hometown:

Hangzhou, China

Research:

Jin designs and builds platforms for the management of computer networks. Network management is a long-standing problem, since network operators have to continuously update network configurations to alleviate congestion, detect and block cyber-attacks, and more. These updates are painful because operators have to balance the tradeoff between the disruption caused by the problem (e.g., congestion and cyber-attacks), and the disruption introduced by fixing the problem. Jin designs elegant, general solutions for transitioning a network from one configuration to another, and builds real systems to evaluate the solutions in practical settings.

Recent honors:

Princeton University's Procter Fellowship; Siebel Foundation Scholar.



MEI CHAI ZHENG

ELECTRICAL ENGINEERING

Hometown:

Brooklyn, New York

Research:

Zheng's research contributes to the development and improvement of devices that sense minute traces of gas for environmental monitoring and medical diagnostics. She works specifically on "quantum cascade" lasers that emit mid-infrared (mid-IR) light to enable more sensitive, compact and affordable sensors. Recently, she created a powerful device that enabled the development of a 3-D sensing and imaging platform, where the mid-IR light emitter not only provides the spectral data for sensing, but also the spatial data for 3-D imaging. Such a hyperspectral imaging system could provide patients with fast and non-invasive biomedical diagnostics without the need for biopsies.

Recent honors:

Harold W. Dodds Fellowship; 2015 Newport Graduate Award for Photonics.



KATIE FITCH

MECHANICAL AND AEROSPACE ENGINEERING

Hometown:

Hamburg, New York

Research:

Fitch's research studies the dynamics and control of multi-agent networked systems such as mobile sensor networks or multi-agent robotic systems. Specifically, she focuses on the underlying graph structure of the networked system, identifying properties of influential sets of nodes. Her work has led to the definition of "joint centrality," a new notion that is key to maximizing a network's robustness to noisy inputs. She also studies which sets of nodes will be able to optimally control the network. Her research demonstrates a fundamental tension in terms of graph properties between the node sets that maximize robustness and those that optimize controllability.

Recent honors:

Larisse Rosentweig Klein Memorial Award; Wu Prize for Academic Excellence.



NANA KOBAY ABOAGYE

OPERATIONS RESEARCH AND FINANCIAL ENGINEERING

Hometown:

Accra, Ghana

Research:

Aboagye works on developing an algorithm to test a finite number of possible responses to a problem with the aim of finding the action with the best performance metric. Examples of such a metric are financial revenue, efficacy of a chemical compound, test scores for a learning technique, and the number of clicks for an online ad. Choice of a particular action results in an observation, called the "reward," which is generated by some unknown underlying function called the "truth." Unlike previous iterations of this algorithm, Aboagye assumes that the truth for each alternative is transient and changing over time. Aboagye seeks to mathematically characterize the behavior of this algorithm.

Recent honor:

Engineering Council Excellence in Teaching Award.

Photos by Frank Wojciechowski

ALUMNI TAKE ON LEADERSHIP ROLES

Linda Abriola

The U.S. Department of State named **Linda Abriola** *83 as science envoy to develop partnerships, improve collaboration, and forge mutually beneficial relationships related to science and economic issues between the United States and other nations. A professor and former dean at Tufts University School of Engineering, Abriola also was named director of Tufts Institute of the Environment. Her Ph.D. is in civil engineering.



Diane Souvaine

Richard Benson '73 was appointed president of the University of Texas-Dallas effective July 15. Formerly dean of Virginia Tech's College of Engineering, Benson earned his BSE in mechanical and aerospace engineering at Princeton.



Ron Brachman

Ron Brachman '71 was appointed director of the Jacobs Technion-Cornell Institute in New York City. Formerly chief scientist at Yahoo and head of Yahoo Labs, Brachman earned his Princeton BSE in electrical engineering.

The TCP Group, a specialty chemical company in Houston, Texas, named **Edward Dineen** *78 as chairman, president, and chief executive officer. Dineen earned a master's in chemical engineering from Princeton.



Eric Schmidt

The National Institutes of Health named **Laura Forese** '83 as chair of its Clinical Center Hospital Board, a panel of external advisors. Forese, who earned her BSE in civil engineering, is the executive vice president and chief operating officer of New York Presbyterian health care system.



Alec Gallimore

Alec Gallimore *92 was named dean of engineering at the University of Michigan, where he succeeds David Munson*79, who had been dean for the last 10 years. Gallimore earned his Princeton Ph.D. in mechanical and aerospace engineering.

Lance Hack '83 has been named chief financial officer at Innovapptive, a mobile software developer in Houston, Texas. Hack earned his BSE in civil engineering.

Michael McCloskey '92 has been named chief financial officer at FusionHealth, a Suwanee, Georgia, company that provides technology to improve sleep and health across large populations. McCloskey earned his BSE in civil engineering and operations research.

James Soss '87 has been named executive vice president at YuMe, an advertising technology company that uses software to place ads across multiple video-viewing platforms. Soss earned his BSE in civil engineering.

Diane Souvaine *84 *86, vice provost for research at Tufts University, has been elected vice chair of the National Science Board, the governing body of the National Science Foundation. She earned her master's in electrical engineering and computer science and her Ph.D. in computer science.

Carl Sparks '89 recently became chief executive officer of Academic Partnerships, an online provider of technology-aided learning for non-profit universities. He earned his Princeton BSE in mechanical and aerospace engineering.

Eric Schmidt '76, executive chair of Alphabet, the parent company of Google, will head the Pentagon's new Defense Innovation Advisory Board formed to provide advice on technology and related innovation to U.S. Secretary of Defense Ash Carter. Schmidt earned his BSE in electrical engineering.



Photo by David Kelly Crow

EMILY CARTER NAMED DEAN OF ENGINEERING SCHOOL

Emily Carter, a Princeton faculty member since 2004 and founding director of the University's Andlinger Center for Energy and the Environment, became dean of the School of Engineering and Applied Science on July 1.

Carter is the Gerhard R. Andlinger Professor in Energy and the Environment and a professor of mechanical and aerospace engineering and applied and computational mathematics. She has earned wide recognition for fundamental research contributions as well as for her vision for harnessing science and policy to produce lasting solutions to societal problems, including those of energy and the environment.

"I'm delighted that Professor Emily Carter has agreed to become the next dean of the School of Engineering and Applied Science," President Christopher L. Eisgruber '83 said in announcing the appointment in April. "She is a brilliant scholar, a capable and proven administrator, and a dynamic champion for engineering at Princeton. Emily's vision and leadership will make her a superb dean at a time when the University is planning major investments in its engineering school."

Carter succeeds H. Vincent Poor *77, the Michael Henry Strater Professor of Electrical Engineering, who served as dean since

2006 and returned to full-time teaching and research.

As director of the Andlinger Center since 2010, Carter led a critical period of growth culminating with the May 18 dedication of the new Andlinger Center for Energy and the Environment building. Created in 2008 and named in recognition of a \$100 million gift from Gerhard Andlinger '52, the center combines science and engineering with public policy and architecture to create solutions to problems of energy and the environment.

Carter has overseen the hiring of the center's staff along with eight faculty members who were jointly appointed with a range of academic departments, the creation of a corporate affiliates program, the start of an undergraduate certificate program, and the launch of a series of technology briefings aimed at policymakers and interested citizenry. She also has spearheaded initiatives in research innovation funding, a speaker series, and internship programs.

"I am immensely grateful to my colleagues and the University administration for their faith in me to lead the already world-class School of Engineering and Applied Science to new heights," Carter said. "Having spent the last six years building the Andlinger Center – from

Emily Carter, who became dean of Princeton University's School of Engineering and Applied Science July 1, was founding director of the Andlinger Center for Energy and the Environment. She gave a talk at the center's Building Opening Celebration and Symposium May 19.

EMILY CARTER NAMED DEAN OF ENGINEERING SCHOOL *(continued from page 1)*

its people to its activities to bricks and mortar – I intend to bring the same collaborative philosophy to Princeton engineering as a whole.”

Provost David S. Lee '99 said he is eager to work with Carter in her new capacity. “Her intellect as a distinguished scientist and her proven experience as an administrator will be crucial to the ongoing strategic thinking about investments in the engineering school in the coming years,” Lee said. “At the same time, as she has been for the Andlinger Center, Professor Carter will be an outstanding representative for the University, advocating for how Princeton engineering, through its teaching and research mission, can contribute to the world and address societal problems of the 21st century.”

Among her many honors, Carter was elected in 2008 to the National Academy of Sciences and the American Academy of Arts

and Sciences and was elected this year to the National Academy of Engineering. She has written more than 300 scientific publications and delivered over 500 invited and plenary lectures worldwide.

“The most challenging problems society faces are thorny, complex, and large, which no single expert will solve on his or her own,” Carter said. “Both in my own research activities and in the Andlinger Center, I’ve sought to catalyze interdisciplinary teamwork as I firmly believe that is how many, if not most, future breakthroughs will occur. But disciplinary cores must be strongly supported as well. At Princeton, we do both. I don’t say lightly that Princeton is – bar none – the best place I have ever seen at fostering interdisciplinary work, at every level. It is a major reason for our outsized impact in the world.” –**Steven Schultz**

Photo by David Kelly Crow



A three-day symposium May 18 to 20 celebrated the opening of the new building for the Andlinger Center for Energy and the Environment. The symposium featured talks by Andlinger Center faculty, who highlighted recent research advances, as well as by academic, government, and industry leaders outlining their visions for the future of energy and the environment. A panel discussion, shown above, covered the center’s preparation of regular written briefings on energy policy and technology.

PROFESSORS LEAD NASA SCIENCE TEAM PROBING UNIVERSE AND PLANETS

Princeton University faculty members have been selected to lead the team of scientists responsible for a major NASA space observatory that will gauge the expansion of the cosmos and plumb the light of distant worlds.

The mission, called the Wide-Field Infrared Space Telescope (WFIRST) project, is scheduled to launch in about 10 years. The telescope will have two broad objectives: to study the nature of dark energy, a substance that scientists believe holds the key to understanding the expansion and, perhaps, the ultimate fate of the universe; and to directly observe and analyze light from planets orbiting distant stars as a way to understand their composition and atmosphere.

“WFIRST is designed to address science areas identified as top priorities by the astronomical community,” said Paul Hertz, director of NASA’s Astrophysics Division in Washington, D.C. “The Wide-Field Instrument will give the telescope the ability to capture a single image with the depth and quality of Hubble, but covering 100 times the area. The coronagraph will provide revolutionary science, capturing the faint but direct images of distant gaseous worlds and super-Earths.”

Two Princeton professors, N. Jeremy Kasdin '85 and David Spergel '82, are leading the teams of outside scientists and experts who are developing the mission. The two jointly hold responsibility for the scientific success of the project, with Kasdin focusing on the observation of exoplanets, and Spergel on the study of dark energy. Kasdin is a professor of mechanical and aerospace engineering and Spergel is the Charles A. Young Professor of Astronomy on the Class of 1897 Foundation.

NASA accelerated the project after the U.S. National Reconnaissance Office made available surplus telescopes that had originally been created for intelligence gathering. One of

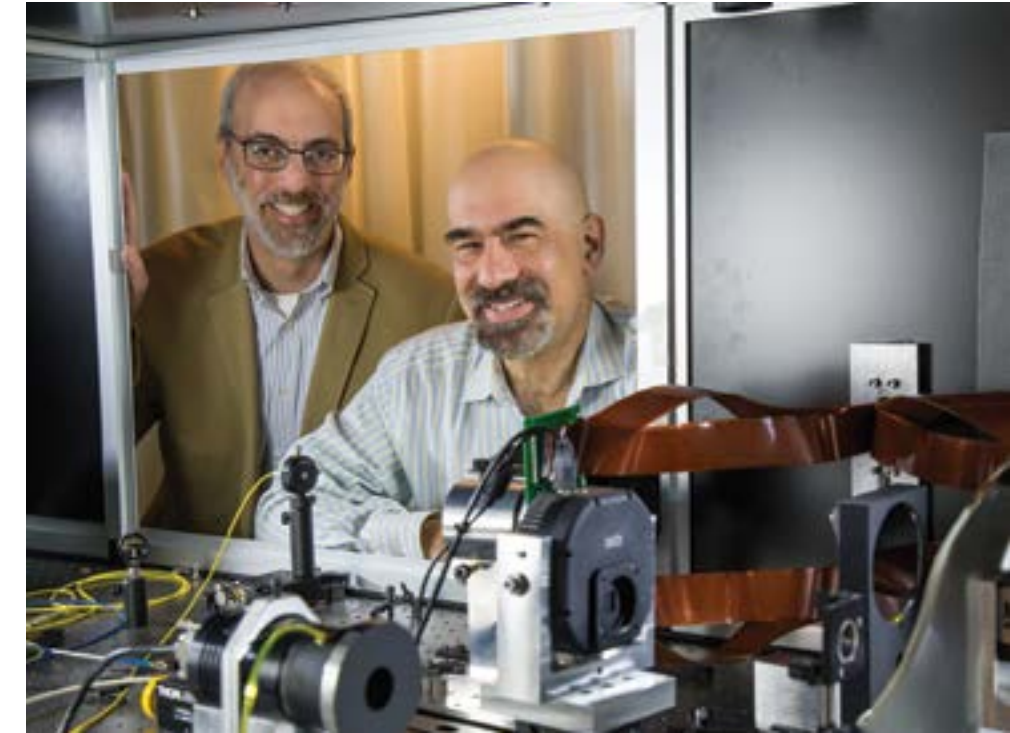


Photo by David Kelly Crow

the scopes – a large, powerful instrument that could survey a broad area of the sky – is being adapted to fulfill the WFIRST mission. Its 2.4-meter mirror (the same size as the Hubble Space Telescope) is being retrofitted to explore questions about dark energy and to examine light from distant planets.

With its coronagraph, WFIRST will be capable of observing planets several times the size of Earth. Kasdin said the long-term goal for projects like WFIRST is to achieve direct observation of Earth-like planets. “It will get us nearer to answering the question of whether we are alone in the universe,” he said. “It is one of the most important questions, scientifically and philosophically, that we have ever asked.” –**John Sullivan**

Princeton professors David Spergel, right, and N. Jeremy Kasdin, left, head a team of scientists designing a major NASA space observatory. The mission, WFIRST (Wide-Field Infrared Survey Telescope), will investigate the nature of dark energy and observe the light from planets orbiting distant stars.

'SCIENCE, SOCIETY, AND DINNER' SEMINAR BRIDGES FOOD, ENVIRONMENT, AND CULTURE

For decades, Craig Shelton has been one of the country's top chefs. But this spring, he took on an additional job: instructor at a Princeton freshman seminar.

After years in restaurants such as Le Bernardin, Bouley, and his own Ryland Inn, Shelton found himself shuttling between home-size electric ranges as he faced Princeton students and a barrage of questions. "Excuse me, chef, is this hot enough? Chef, what order do we cook these in? How do I slice this?"

Shelton was thrilled.

"You can't teach people about food only through books," he said after one class. "But to really understand food, and to understand the challenges of food and society, you can't just stay in the kitchen."

The course – "Science, Society and Dinner" – introduces students to the basics of knife skills, sautéing, and palate education, as

well as the water cycle, sustainable agriculture, and the biochemistry of taste – and how it all fits together.

"We are teaching people to understand the inputs of water and energy and carbon that go into creating their diets," said Kelly Caylor, an associate professor of civil and environmental engineering and director of the Program in Environmental Studies, who was the course's co-instructor. "When you make the choice between tomatoes from a local greenhouse or tomatoes from Mexico, what are the tradeoffs? What are the costs?"

As Shelton said, you can't learn about food without getting your hands dirty. So one night a week, the students sliced, fried, baked, and ate together. But before that, they listened as guest lecturers spoke about the science of food – the chemistry, social tradeoffs, and history. Field trips took them to local farms.

The course grew from a mix of student, community, and faculty initiatives. Karla Cook, of the Princeton Studies Food consortium, envisioned the course, and rising junior Rozalie Czesana, also of the consortium, proposed it as a seminar. Caylor signed on as the lead teacher and four other faculty members from the sciences, humanities, and public policy gave guest lectures. The course received support from the Office of the Dean of the College and the R. Gordon Douglas, Jr. '55 P86 and Sheila Mahoney S55 Fund.

"The course uses the community of the table to drive the science," said Cook, a longtime food journalist formerly of The New York Times, noting that issues such as climate change require bridging personal choices and scientific understanding. "If outrageously delicious food, with its art, its very human story, and its scientific requirements can move the needle and motivate students in their personal and professional lives, we're ready to cook." –JS

Photos by Karla Cook



In "Science, Society, and Dinner," first-year students studied the balance of food, economics, the environment, and culture in alternating sessions in the classroom and in the kitchen.

TIGHTLY SPACED OBJECTS COULD EXCHANGE MILLIONS OF TIMES MORE HEAT



Photo by Frank Wojciechowski

Alejandro Rodriguez (left), assistant professor of electrical engineering, found that microscopically close objects can radiate 1 million times more heat between each other than previously believed. Graduate student Prashanth Venkataram (right) uses related mathematics to extend the work to other types of energy transfer.

The sun's warmth crosses millions of miles of space to create a summer day; a campfire roasts marshmallows from several feet away. Scientists have understood the mathematics behind this ghostly heat transfer since the 19th century. But that math breaks down at very close quarters – within nano-scale electronics and solar-electricity cells where heat transfer is critical.

Researchers at Princeton and the Massachusetts Institute of Technology have developed a formula that describes the maximum heat transfer in such tight scenarios. Surprisingly – and encouragingly – the formula suggests that a million times more heat transfer is possible between close objects than previously thought.

"We now have a ceiling for how much heat transfer we can expect," said Alejandro Rodriguez, an assistant professor of electrical engineering at Princeton. "The fact that this ceiling is several orders of magnitude higher than has been previously demonstrated in existing material structures is extremely promising."

The formula is the first major amendment to the math that describes radiative heating – the Stefan-Boltzmann law – since it was established in 1879. With this new formula, engineers will know how to squeeze more out of their structural and material designs. Potential uses include converting heat into electricity, as well as cooling electronics such as processors.

Rodriguez's group at Princeton focuses on manipulating the interactions of light and matter at nanoscales. Typically, warm objects emit infrared light, which carries heat to other objects. At distances of less than the infrared wavelength, about eight microns, another type of radiation called evanescent waves takes over, Rodriguez explained. The new law accounts for the properties of evanescent waves.

"I am very optimistic that we will be able to come very close to reaching the limits both for near-field heat transfer and frequency conversion," said Rodriguez. "That's the spirit of much of the work I'm doing here at Princeton." –Adam Hadhazy

STUDENTS FIND CREATIVITY AT INTERSECTION OF ART AND ENGINEERING IN NEW COURSE

Photo by David Kelly Crow



From left, students Noah Fishman, Nora Bradley, and Sunny He designed a device that allows visually impaired people to experience color.

Inspired by the desire to help vision-impaired people experience color, three undergraduates created an arm-band device that allows its wearer to interpret color without the ability to see. The project emerged from a new class, “Transformations in Engineering and the Arts,” and lived up to the name of the course. In addition to transforming the sensation of color from a visual to a tactile experience, the students transformed an idea born on a whiteboard into a product that interweaves engineering concepts and artistic practices.

“Having a forum where our imagination is the limit has been an incredible experience,” said Nora Bradley, a sophomore in mechanical and aerospace engineering who worked with senior music major Noah Fishman and sophomore Sunny He of electrical engineering.

The team’s device uses a sensor to identify whatever color passes under it, then “displays” the hue by turning a rotary dial labeled in Braille.

A partnership between the Council on Science and Technology, the School of Engineering and Applied Science, the Department of Music, and the Lewis Center for the Arts, the class stemmed from several conversations among faculty and students interested in the intersection of arts and engineering.

“We were focused on leveraging a combination of the creative processes we use in engineering and the arts with ‘transformations’ as our framework,” said Naomi Ehrich Leonard ’85, who led the development of the course and is the Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering and director of the Council on Science and Technology. “For example, the students designed artful visualizations of sound and compositions that were translations of movement into sound,” she said. “It’s about working across disciplinary boundaries and not being confined to just one academic identification.”

The inaugural spring class was organized around four modules in the first half of the semester: visuals, sound, structure, and movement. These modules, led by faculty across the disciplines, included lectures, hands-on activities, discussions of aesthetics, mini design challenges, and tutorials on tools and resources available in a newly created teaching space called StudioLab. In the second half of the semester, students defined their own questions and created independent projects.

After junior Max Greenwald demonstrated his final project – a game that combined motion-tracking technology, theater lighting, and computer-game design – he said the best part of the class was the opportunity to play. “This project really energized me to be a maker and a doer and physically create something,” he said. “I couldn’t be more thankful to the class for allowing me to create something like this.” –**Catherine Shen**

FLUID SELF-ORGANIZES INTO STRUCTURE THAT CONTROLS CELL GROWTH AND HEALTH

Although known since the 1830s as a round, dark spot in a cell’s nucleus, only recently has the nucleolus gotten its full due. Scientists have learned that besides building a cell’s protein factories, this specialized subunit, or organelle, serves more broadly as a control center for cellular growth and health.

In the last several years amid a flurry of research, Princeton’s Clifford Brangwynne and colleagues discovered that the nucleolus behaves like a liquid with the consistency of honey. Yet somehow, this biological droplet maintains a complex, compartmentalized internal structure. Brangwynne, an assistant professor of chemical and biological engineering, and other researchers have puzzled over how such a liquid-like object could develop stably compartmentalized layers, rather than just fusing into a homogenous glob.

A new study by Brangwynne, his students, and their collaborators presents a solution to the paradox of nucleolar assembly and internal organization. Their paper, published online May 19 in the journal *Cell*, shows that the constituent proteins and RNA of nucleoli spontaneously assemble themselves into three distinct liquid layers thanks to their differing properties, such as surface tension and viscosity. Rather like how oil and water can coexist yet remain separate, the nucleolus develops liquid sub-compartments that enable its critical functions. These insights into the nucleolus’ form and function could ultimately point toward new ways to treat disease.

Photo by Frank Wojciechowski



“To get the characteristic layered, ‘core-shell’ architecture of the nucleolus, all you need to do is mix the right molecules together at sufficient concentrations,” said study co-lead author Marina Feric, a Ph.D. student in chemical and biological engineering.

“We’ve provided a biophysical mechanism for the structure of the nucleolus that automatically emerges from the collective behavior of immiscible liquids,” said the study’s other co-lead author, Nilesch Vaidya, a Helen Hay Whitney Postdoctoral Fellow in Brangwynne’s lab.

Brangwynne and colleagues had previously shown that a number of other organelles besides the nucleolus also are phase-separated liquid droplets of RNA and protein. The present findings point to how these organelles, all of which lack the obvious compartmentalization offered by membranes, can nevertheless exhibit intricate architectures tailored for their cellular duties.

“The basic properties of fluids dictate which components of the nucleolus are on the inside and the outside,” Brangwynne said. “Since the fundamental principles underlying this effect are observed even in non-living states of matter, we think this physical picture applies to many organelles inside cells.” –**AH**

Clifford Brangwynne’s research team at Princeton University has demonstrated that the nucleolus, an important cellular body, has a complex internal structure despite being made entirely of liquid. Far right: Brangwynne, an assistant professor of chemical and biological engineering, is shown with, from left, lab members Marina Feric and Lian Zhu, Ph.D. candidates, and Tiffany Richardson, Class of 2017.

‘EXTRAORDINARY PROCESSES’ COURSE LINKS ART AND ENGINEERING

Tension mounted at the Lewis Center for the Arts’ Lucas Gallery as Julia Wilcots, a civil and environmental engineering major, hung small sandbags from the graceful wood bridge that spanned the gallery’s clean white walls.

The bridge – thin strips of ash crossed in an X and mounted at their four ends – bowed and shimmied with each new weight. Its stresses and deflections seemed to transmit directly into the intently watching students gathered for the final session of “Extraordinary Processes,” a seminar offered jointly by the Program in Visual Arts and the Department of Civil and Environmental Engineering.

Having succeeded in meeting the course requirement of loading the bridge with 16 pounds, Wilcots and fellow student Neeta Patel tried radically shifting all the weight to one end, and Wilcots could not bring herself

to fully release her hand from the last weight as the asymmetrical structure danced near the edge of its stability.

“Go for it,” said Patel, a senior majoring in Program 2 studio arts in the Department of Art and Archaeology and Wilcots’ partner in making the bridge.

“I love it,” said Joe Scanlan, director of the Program in Visual Arts who co-taught the class this fall. “The artist is saying ‘Let go!’”

It was the sort of moment that Scanlan and his collaborator Sigrid Adriaenssens, associate professor of civil and environmental engineering, had hoped for as they invented a course to nudge students beyond their comfort zones at the boundary of art and engineering. The two chose to work with the wood of ash trees as a theme that was not grounded specifically in either art or engineering, but allowed an exploration of both.

During the semester, the students heard talks by experts on the emerald ash borer, an insect that is destroying ash trees, and visited the studios of legendary woodworker George Nakashima in New Hope, Pennsylvania. They built an apparatus to steam-bend wood and conducted labs that explored the difference between mathematical predictions and actual experience. They made self-portraits out of ash and culminated the semester with the bridge project.

“To work with one material so intensively for one semester is really enriching,” Adriaenssens said. Immersed in cutting, carving, bending, weaving, buckling, and simply handling the ash wood, the students’ creativity grew.

As the semester progressed, Scanlan said, arts students developed forceful ideas about measurement and utility, and engineers appreciated the aesthetic success possible even in a failed structural test.

“In the end there was not so much a split – here is an engineer and here is an artist,” Adriaenssens said. “The boundaries softened and the two had really merged.” **–SS**

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**REVOLUTION
LEADS TO BETTER DECISIONS,
INNOVATIVE SOLUTIONS**

by Jennifer Rexford '91

Society floats in a sea of data.

This magazine, the words printed in it, the photos displayed, all passed as ones and zeroes through the digital realm. The printing presses, the rolls of paper, the delivery trucks were created and managed with digital tools. But it does not stop there. These processes also left trails of data in their wakes, ripe for untold analysis. Modern society could no more run without data than without oxygen.

Data, the plural form of the Latin word meaning “given,” is obviously not a new concept for scientists. Factual observation has been the keystone of Western science since Francis Bacon opened his lab. But computation has altered science and engineering’s relation with data in ways as fundamental as Bacon’s original idea that science

should be founded on empirical observation rather than philosophy. By harnessing the power of modern computers and algorithms, researchers collect, store, and analyze data in entirely new ways – to amplify discovery and illuminate truths that were invisible before. New ways to extract meaning from data offer a promise of better decisions at all levels of science and society, and thus solutions to countless societal challenges.

In this issue of *EQuad News*, we see the vast scope of change that the data revolution has brought to science and engineering. Barbara Engelhardt is using computation to explore human genetic expression and its effect on the body’s systems (page 18); Clifford Brangwynne has combined computer modeling with lab work to bring new under-

Photo by Frank Wojciechowski



Neeta Patel, an art and archaeology major (left), and Julia Wilcots, a civil and environmental engineering major (right), hang weights from their bridge in the Lucas Gallery of the Lewis Center for the Arts as part of the class “Extraordinary Processes.”

DATA REVOLUTION LEADS TO BETTER DECISIONS, INNOVATIVE SOLUTIONS (continued from page 9)

standing to critical cellular functions (page 7); and two mechanical and aerospace engineers are developing methods to control unruly plasma particles as a step to harnessing fusion energy (page 20).

Han Liu's research team is developing new rules for big data analysis as a way to construct systems that find patterns as varied as genetic markers for autism and efficient trading for financial markets (page 14); Naomi Ehrlich Leonard's '85 work examines how many individuals with tiny data processing ability can form large groups to perform incredibly complex tasks (page 17); and Andrew Houck's '00 lab is seeking to change the nature of data and computation based on the strange rules of quantum physics (page 19).

We also see how much work remains to increase data's value as a tool and prevent abuse in how it is used. As computer programs increase in complexity, the group of Andrew Appel '81 is developing methods to root out software problems before they occur (page 16); Nick Feamster's team at the Center for Information Technology Policy is working to ensure that the internet remains an effective global platform for accessing and delivering data, without compromising our privacy or security in the process (page 15).

And, critically, we see how the data revolution is driving advances that benefit people around the globe. Warren Powell '77 is helping electric companies in Brazil integrate wind power into their grid (page 12); Eric Wood and Justin Sheffield are developing a flood warning system to prevent disasters in Chile

(page 11); and David Wentzlaff's team has developed an innovative tool to allow scientists around the world to develop new microchips without the need for expensive fabrication (page 14).

The Canadian philosopher Marshall McLuhan said that human society and actions are shaped by our tools of communication. Just as the internet and wireless technology have borne out McLuhan's observation countless times over, our ever-growing ability to collect and analyze diverse data, and uncover their meaning, will alter society in ways so profound we can hardly imagine them today. **E**



Photo by David Kelly Crow

Jennifer Rexford '91 is chair of the Department of Computer Science and the Gordon Y.S. Wu Professor in Engineering



Photo by VLADIMIR RODAS/AFP/Getty Images

FLOOD WARNING SYSTEM TO HELP EMERGENCY DECISIONS IN SOUTH AMERICA

by John Sullivan

In the summer of 2015, a freak cold front swept across the Andes and poured rain that triggered flash floods across parts of Peru and northern Chile. The floodwaters overflowed streambeds and sent mudslides roaring through rural communities. In the aftermath, the Chilean government estimated that more than 27,000 people were displaced.

The following spring, a team of Princeton researchers traveled to Chile to meet with scientists there and begin constructing a new flood warning system for the country. Led by Eric Wood, the Susan Dod Brown Professor of Civil and Environmental Engineering, and Research Scholar Justin Sheffield, the team hopes to help Chile plan for and respond to similar disasters in the future.

"The goal is to take our existing continental-scale model for Latin America and to increase spatial resolution to focus on Chile and provide the foundation for an operational system," said Wood, whose team previously developed hydrological monitoring systems for Africa, Latin America and the Caribbean, and the continental United States. "It will cover the entire country at a high spatial resolution, and our hope is that regular people can get direct access to the information."

Sheffield said the team plans to assemble an online system, including maps, that will

predict flooding seven to 14 days in advance. "It will be an operational forecasting system," he said.

The project is an outgrowth of work that Wood and Sheffield have done in recent years predicting drought in Africa. The researchers have developed sophisticated models that combine historic climate-station data, satellite information, and field reports to forecast droughts and estimate their severity.

"One of the challenges, and one of the most exciting things, is bringing together these very diverse sources of data," Sheffield said.

In Chile's case, the government has a sophisticated weather forecasting system as well as river and rain gauges that the Princeton team will work to integrate with satellite data. The team also will help develop a system to interpret data and pass them along to users. Wood and Sheffield said that it is critical for the system to present information reliably and understandably. For the system to be of value, citizens and community leaders must have access to information they need to cope with floods or droughts.

"We are doing the science, but we also have to bring the information to the people on the ground who are making the decisions," Sheffield said. **E**

Princeton researchers combined satellite data with data from government weather systems and river and rain gauges to predict flooding in South America and avoid the worst consequences of events such as the flooding shown here in Santiago, Chile, on April 27, 2015, which left 4 million people without water.

OPTIMIZATION EXPERT HELPS BRAZIL WITH ELECTRICITY- SUPPLY PROBLEMS

by John Sullivan

The historic drought that parched Brazil over the past two years was not just a water-supply problem – it was also a power problem.

The nation's heavy use of hydroelectricity, which had made it a model of renewable energy, contributed to rolling blackouts in some of Brazil's largest cities during severe droughts. Now, Princeton researchers are joining colleagues at a Brazilian university to help the operator of Brazil's electricity grid and the country's major utilities develop a system to better manage their electric system when hydropower dries up.

Warren Powell '77, a professor of operations research and financial engineering, and colleagues at the University of Campinas are analyzing plans for integrating new types of renewable energy into the Brazilian electricity grid. Powell, whose work focuses on optimization and uncertainty, has done extensive

research on electricity distribution systems. Among other topics, Powell has analyzed the PJM Interconnection – the massive grid that supports an area from the Mid-Atlantic states to the Ohio Valley. A group of 19 electric-power generation companies in Brazil asked for Powell's help in managing their own system, particularly how to integrate wind power into the grid.

"The Brazilians are the world's experts at modeling hydropower," Powell said. "But they need mechanisms to deal with the variability of wind power."

Managing an electricity grid is far more complex than turning on the power. The amount of power running through the system has to be carefully balanced to prevent shortfalls on one hand and wasted energy on the other. As the systems get larger, the job becomes more complicated. In the United States, grids are coordinated by federally regulated groups called Independent System Operators. The PJM Interconnection, for example, has over 61 million customers and coordinates roughly 1,300 power generators ranging from small solar fields to massive nuclear plants.

Matching power supply and demand requires that grid operators contend with fluctuations that occur seasonally, daily, and hourly. The balancing act becomes more challenging as grids integrate more renewable power sources, which can be more intermittent than traditional power plants.

A successful model, Powell said, will help operators create a system with enough options that extreme stress in one area, such as a drought, would not leave the grid crippled. To be effective, the system needs to reflect its environment as well as power demand.

"The Midwest has ethanol, Florida has solar, and the New England has hydropower from Quebec. We need to learn what Brazil has," he said. "We want to help Brazil develop a portfolio with enough options so there is always something to turn to." **E**



Photo by David Kelly Crow

Warren Powell, a professor of operations research and financial engineering who has done extensive research on electricity distribution systems, is helping Brazilian power companies smoothly integrate more wind power into their electric grid. Above, Powell talks with Nana Aboagye, a fourth-year Ph.D. student in operations research and financial engineering and member of his research group.

In Africa, where countries strive to expand agriculture to keep up with growing populations, data are a key element in mapping plans to provide food for billions.

Despite improvement in agriculture in many African countries, urban population across the continent has tripled over the past 30 years, leading to a net decrease in key food exports. The African Union estimates that 80 percent of farms in Africa are family-run operations of less than five acres.

This can make it extremely difficult for governments and regional organizations to plan for expansion and cope with demands for water and arable land. Kelly Caylor, associate professor of civil and environmental engineering, said that if political leaders don't have a good idea of the type of crops farmers are growing or the land they are using, policies could end up damaging agriculture in the long run.

"Improving the capacity to monitor the spatial distribution of agriculture, particularly among smallholder farmers, is critical to increasing agricultural productivity and food security," Caylor and other researchers wrote in a recent article in the journal *Remote Sensing of Environment*.

To address the problem, Caylor's team at Princeton has been working on several fronts. In the Mapping Africa project, researchers are asking internet users to help comb through satellite maps to identify different types of land use in certain regions. In other efforts, researchers are developing new techniques to identify land use by combining satellite imaging with other data.

Photos courtesy of Kelly Caylor



INTEGRATING CROP DATA AIDS FOOD SECURITY IN AFRICA

by John Sullivan



A sensor system developed at Princeton became the basis of a company, Arable, which allows farmers to collect critical data on crops. Adam Wolf (lower right) created the company with Ben Siegfried '12 (middle left) and Associate Professor Kelly Caylor, whose research assistants Ekomwa Akuwamand and Julia Signell (upper right) collected data in Kenya.



Photo by Frank Wojciechowski

Han Liu, assistant professor of operations research and financial engineering, is developing new mathematical tools that will allow other researchers to analyze complex scientific and business data with the weakest possible assumptions.

NEW MATH LETS DATA TAKE THE LEAD

“Big Data,” the use of powerful computation to find insights in massive fields of information, is in many ways a new science. As such, Han Liu said, it requires a new approach in mathematics.

“Things are starting to change and change fundamentally,” said Liu, an assistant professor of operations research and financial engineering.

For centuries, science has followed the same pattern: Scientists make conjectures, test them, and try to disprove their hypotheses. Big Data has changed that process.

“People are collecting large amounts of data. They analyze the data to find hidden patterns and use the patterns to lead to new hypotheses,” Liu said. “Many of these hypotheses are very counterintuitive and surprising.”

These new methods rely on statistics and probability and on advanced computing techniques in which the data “train” computers to interact with them so that future sets of data yield even greater results.

Scientists are already using this approach for many problems, from researching artificial intelligence to probing the genetic background of complex diseases and biological processes. The successful programs can find patterns that human intuition cannot see. But Liu said that most of the work is still very focused on applications.

In his Statistical Machine Learning Lab, Liu and his team are developing broad analytic tools that allow researchers to analyze complex scientific and business data with the weakest possible assumptions. In particular, they use data and computation as lenses to explore science and machine intelligence. “We need to build fundamental principles to make this a solid field,” Liu said.

Liu said that the current generation of students will play a critical role as Big Data develops as a science. “We are not trying to teach them techniques, but to be smarter, to be deep thinkers,” he said. **–JS**

TOOL EXPANDS ACCESS TO THE FIELD OF CHIP DESIGN

David Wentzloff devotes most of his research to designing new computers, but this year his team did something different: They developed a tool that allows others unprecedented ability to create their own sophisticated computer chips.

Wentzloff and his team created the system, called OpenPiton, after they realized there were almost no simple ways for chip designers – outside major corporations – to experiment with complex “manycore” systems, which have many processing units on the same chip.

“OpenPiton allows them to do all the research, from start to finish, using a single platform,” said Jonathan Balkind, a graduate student in Wentzloff’s team.

The project’s name comes from Wentzloff’s passion outside the laboratory: mountaineering. A piton is a spike driven into rock to

RESEARCHERS REVEAL ESCALATION IN CAT-AND-MOUSE GAME OF INTERNET CENSORSHIP

Researchers have found that the “Great Firewall” technology that controls internet traffic entering and leaving China is not merely an apparatus that statically blocks traffic. It also actively sends probes across the internet, preemptively searching for internet infrastructure and services that seek to circumvent its defenses.

“The Great Firewall is actively trying to find these sites so it can block them,” said Nick Feamster, a professor of computer science at Princeton and the acting director of the University’s Center for Information Technology Policy. “Active reconnaissance is the next step in the arms race,” he said.

In contrast to the decentralized management that characterizes much of the internet, China’s internet is tightly controlled: Traffic entering and leaving the country passes through infrastructure in just a few physical locations.

“It allows the Chinese government to see most traffic between China and the rest of the world,” said Roya Ensafi, a postdoctoral researcher who worked on the project.

To avoid this control, citizens often use online systems that encrypt communications and disguise sites visited. Princeton researchers have found that the government has responded to this with sophisticated efforts to identify and block these systems, leading to an online game of cat and mouse.

“It is an ongoing battle,” Ensafi said. **–JS**

Photo by Frank Wojciechowski



From left, Princeton researchers Roya Ensafi, a postdoctoral researcher in computer science, and Nick Feamster, a professor of computer science, are investigating methods that the Chinese government uses to control computer communications entering China from the rest of the world.



Photo courtesy of David Wentzloff

assist climbers on an ascent. The name OpenPiton reflects the team’s desire to offer tools that help others develop their ideas.

“We want to give people the tools they need to develop their own manycore processor designs,” said Wentzloff, assistant professor of electrical engineering. “OpenPiton is a first of its kind and by opening up our designs to people around the world we hope to spur huge innovation.”

In recent years, the performance of a single processor core has stopped increasing. So designers have increasingly begun using multicore and manycore systems that rely on spreading out computation across multiple separate processor cores.

“Instead of having faster cores, you have more of them,” said Mohammad Shahrads, another of Wentzloff’s graduate students.

another of Wentzloff’s graduate students.

Multicore and manycore systems require careful coordination among the cores to function properly, so their designs are often more complex than uni-processor systems. Wentzloff said until now there was no training program or reference design available for students or independent designers to build their own or experiment with multicore or manycore processors. His team tested OpenPiton by developing and fabricating a chip with 25 cores. The OpenPiton framework is available through the lab’s website (<http://parallel.princeton.edu/openpiton/>).

“Anyone, whether researcher or hobbyist, can use it,” Shahrads said. “It is completely open-source. That’s the goal of the project.” **–JS**

David Wentzloff, assistant professor of electrical engineering, led his team in creating an open-source tool that allows researchers to design sophisticated computer chips with far fewer resources than previously needed. Outside the lab, Wentzloff leads his team on mountaineering expeditions, which inspired the name of the chip-building tool, OpenPiton.

COMPUTER SCIENTISTS LAUNCH CAMPAIGN TO GUARANTEE BUG-FREE SOFTWARE

by Doug Hulette

Andrew Appel (center), professor of computer science, is leading a project called DeepSpec, which aims to eliminate bugs in complex software.

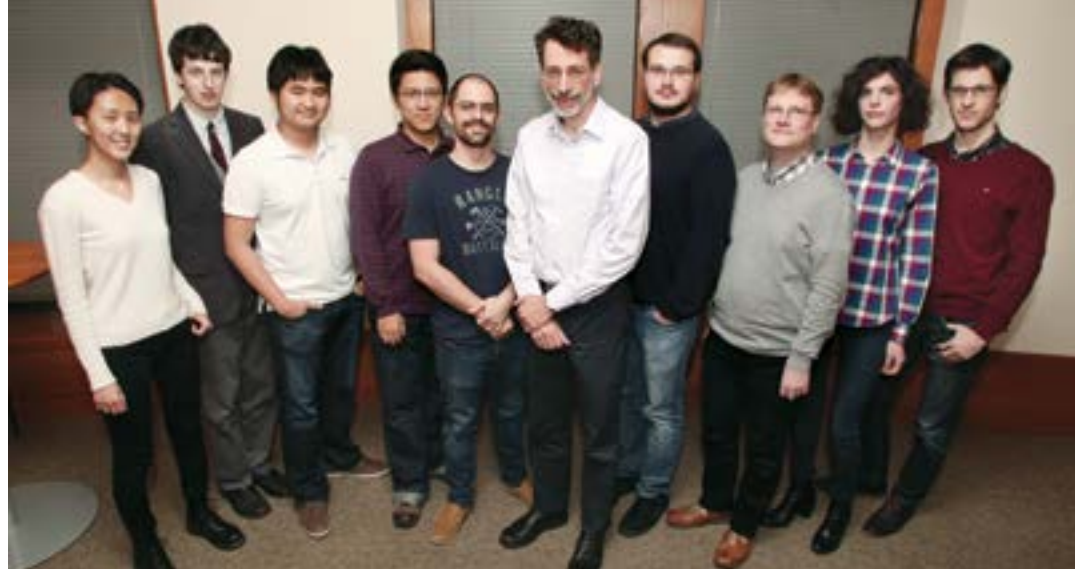


Photo by Frank Wojciechowski

The next time a software maker says to update your favorite computer application to fix defects or patch security holes, don't lose faith. Help is on the way.

A team led by Princeton computer scientist Andrew Appel '81 aims to exterminate software "bugs," the maddening programming errors that can open systems to hackers; disable cellphones, cars, and electronic devices; and cause errors in critical tasks such as tabulating election returns.

Funded by a \$10 million, five-year grant from the National Science Foundation, Appel and colleagues at the University of Pennsylvania, Yale University, and the Massachusetts Institute of Technology are developing integrated tools to eliminate uncertainty from the complex task of software development. A goal of the project, known as DeepSpec, is to reshape the industry by erasing the gap between researchers, who have made progress in the fight against bugs, and educators who are teaching the next generation of programmers.

"In our interconnected world, software bugs and security vulnerabilities pose enormous costs and risks," said Appel, the Eugene Higgins Professor of Computer Science. "When you press the accelerator pedal or the brake in a modern car, for instance, you're really just suggesting to some computer program that you want to speed up or slow down. The computer had better get it right."

The team's initial challenge is to dissect the overwhelming complexity of modern hardware and software to uncover factors that determine how computer components work together. The next step is to develop "deep specifications" – precise descriptions of software behavior – that will enable engineers to build and verify bug-free programs.

In a way, the project marks a shift in an industry in which many software writers work on isolated tasks and don't annotate their coding in ways to allow others to learn from their thinking. This weak institutional knowledge base has slowed progress toward a solution to the riddle of unintended consequences, especially in complex situations that involve multiple programs working at the same time, Appel said.

While the DeepSpec project is committed to promulgating its findings throughout the computer industry, a key will be changing what's taught in colleges and universities.

"Students in these courses will learn more, with less effort, because the DeepSpec approach allows us to clarify how the pieces fit together," Appel said. "I'm looking forward to test-driving this new curriculum at Princeton, to evaluate how much of a difference it makes." **E**

What does dance have to do with data?

Quite a lot, says Naomi Ehrich Leonard '85, the Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering.

Leonard studies the collective motion of groups such as dancers, starlings, or fish to better understand their decision making. Starling flocks, which swirl and twist like smoke, avoid predators and find food without direct communication between the birds. The group develops complex strategies and responds rapidly to external challenges.

"It's fascinating, and it seems to produce the type of collective behavior that we seek to create when we design distributed strategies for robotic systems that have to perform in complex environments," said Leonard. Examples of such complex environments include robotic exploration of the oceans or wide-scale environmental monitoring.

Leonard and her research team study how groups arrive at collective decisions and create models to evaluate various sets of rules that govern behavior. In the case of starling flocks, they found that consensus is most accurate and efficient when each starling adjusts its direction in response to observations of six or seven of its closest neighbors. Studying schools of fish, the group found that killifish exhibit coordinated oscillations in their motion and showed that this provides an advantage in how fast the fish come to a consensus.

"We combine the analysis of data with mathematical models to help us understand and predict behavior," Leonard said. "We can use the models to ask further questions and systematically gain a better understanding of mechanisms that explain what is observed and what is possible in design."

Dance also provides rich opportunities for studying and inspiring collective dynamics. Leonard recently collaborated on "There Might

Be Others," a dance work choreographed and directed by Rebecca Lazier, senior lecturer in the Program in Dance, with music composed by Dan Trueman '99, a professor of music.

In this work, which was performed in March at New York Live Arts in New York City, dancers make collaborative compositional choices in the moment.

Modeling and analysis not only help to understand collective decisions, they also provide insights into how to facilitate or influence the creative choices the artists make towards artistic goals.

"We explore the sensitivities of the group dynamics," Leonard said. "What makes it work? What makes it interesting? What makes it beautiful?" **E**

DATA YIELDS INSIGHT INTO BEAUTY AND POWER OF COLLECTIVE MOVEMENT

by John Sullivan

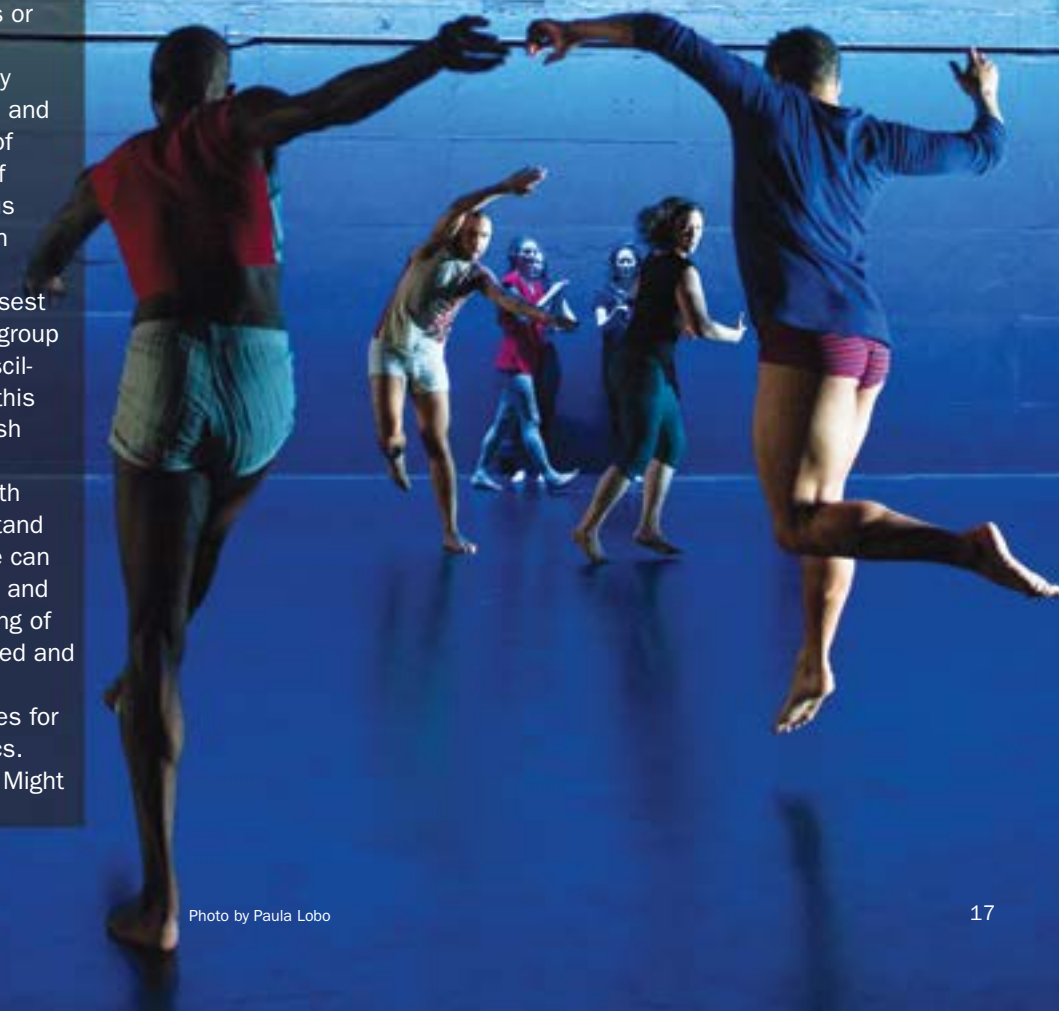


Photo by Paula Lobo

STATISTICAL TECHNIQUES ISOLATE ROLES OF GENES IN HUMAN TISSUES

by John Sullivan

Computer scientist Barbara Engelhardt (center) leads a research group that is deciphering gene-expression data, as well as data about other complex traits and disease.



Photo by Frank Wojciechowski

Trying to unravel the roles that a small set of genes plays in the regulation of a human trait is a daunting enough task, but when scientists try to apply the same analytic methods to a specific tissue or organ, they quickly run into a storm of information.

The functional role of any one gene is quickly obscured by a cascade of genes whose influence combines with that of other genes and environmental factors to affect multiple pathways. What starts as a few bits of information quickly becomes a blizzard of complex structured interactions.

“It’s really a needle in a haystack,” said Barbara Engelhardt, an assistant professor of computer science.

Engelhardt’s research group specializes in handling statistically difficult problems such as deciphering gene expression data, as well as data about other complex traits and disease. One of the great challenges of her work is finding subtle patterns among relatively small numbers of samples – even a large clinical trial might involve only a few thousand people, but tens of thousands of genes and millions of genetic mutations.

“Statistics in general has been developed for very large data sets – a billion Facebook

users, a trillion Google queries,” Engelhardt said. In most biological systems, on the other hand, “we don’t have an infinite amount of samples because of the cost to acquire each one.”

With relatively small pools of data, it can be difficult to separate biologically important patterns from random noise or technical effects. To address these problems, Engelhardt’s team harnesses the power of computation with innovative statistical methods. Identifying and characterizing these latent patterns can help scientists understand key mechanistic relationships in immense fields of data. Recent work has looked at the interactions of multiple genes in breast cancer, neuropsychiatric diseases and metabolic diseases.

“We are developing statistical methods to separate the structured noise from the signal,” she said. “We want to figure out the interactions driving disease from subtle patterns within the data.” **E**

Most scientists who work closely with data try to improve ways to process it or to harness it for other, broader inquiries.

Andrew Houck ’00 and his team are taking a different approach: they are trying to change the nature of data itself.

Houck, a professor of electrical engineering, and colleagues are seeking to build a quantum computer, a new type of machine that uses the strange rules of quantum mechanics to address problems that are not possible to solve with standard computers.

“Normally, when you think of a computer, you are thinking of a machine that stores information in binary, a series of zeroes and ones,” Houck said. “A quantum computer is one that processes an entirely new kind of information. It is not restricted to ones and zeros – because of the laws of quantum mechanics, it can be both zero and one at the same time.”

In a quantum computer, each of the quantum bits, or qubits, remains in this uncertain state until their value is measured by the computer, at which point they switch to become either a zero or a one. This unusual behavior allows mathematicians to write unique programs that predict the probability of a qubit assuming a value and to build that probability into a final result.

“The magic is when you measure this thing it forces your answer to become a discrete outcome,” Houck said. The math is complex but, as Houck noted, “if you run the algorithm just right, you can answer certain questions really efficiently, and these questions are very difficult to handle on classical computers.”

Possible uses include powerful code-breaking systems or solutions to key biological questions such as how proteins acquire their three-dimensional shapes.

An illustration by researchers in the lab of Andrew Houck depicts a new technique to measure photons – particles of light – in a superconducting quantum simulator, a form of quantum computing.

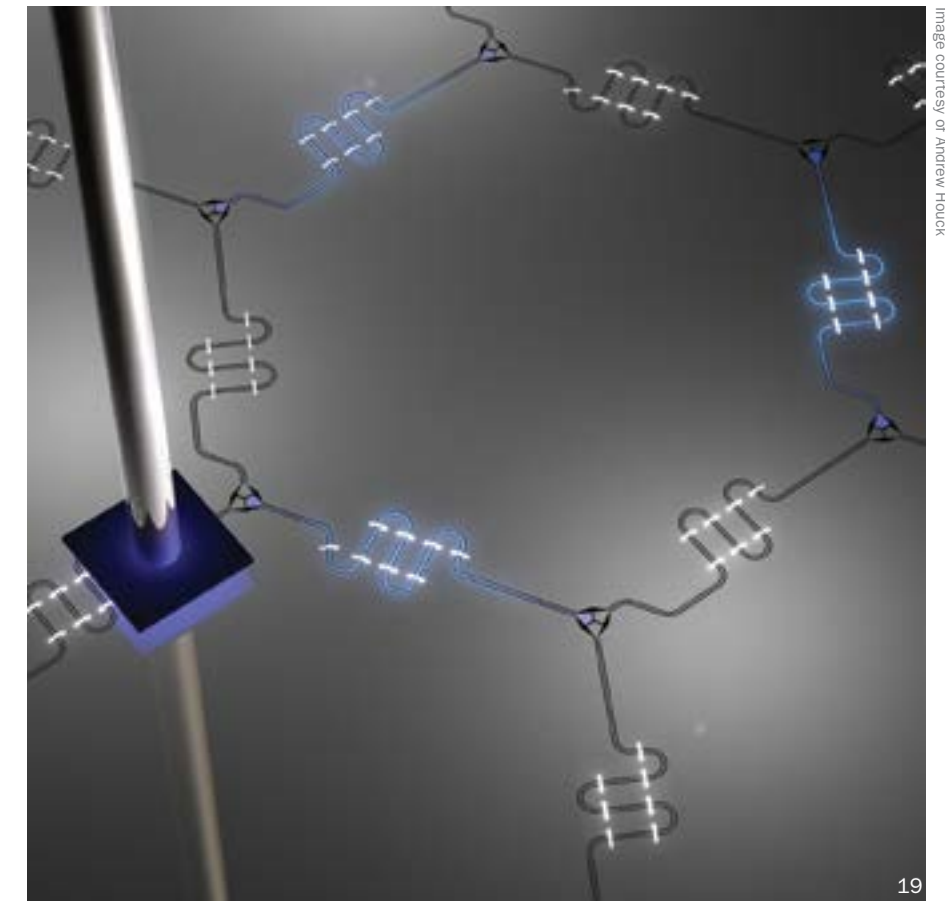


Image courtesy of Andrew Houck

BEYOND ONES AND ZEROES: QUANTUM DATA PROMISE NEW REALM OF PROBLEM-SOLVING

by John Sullivan

Houck, whose team is experimenting with superconductors and patterned metal to develop a new machine, said that quantum computers already have been built to address certain problems. The question is, when will engineers achieve “quantum supremacy” by building a machine that solves a problem more efficiently than the best standard computer? Houck believes that could happen within a decade. He cautioned that the first solution might not be groundbreaking, but it could provide an entirely new tool for science.

“It probably will not be a problem that anyone cares about,” Houck said. “But it will be a problem that we could not otherwise have solved.” **E**

DATA DRIVE QUEST TO CONTROL NUCLEAR FUSION

by John Sullivan



Photo by Frank Wojciechowski

Egemen Kolemen (left), assistant professor of mechanical and aerospace engineering, speaks with Al von Halle, head of engineering and operations for NSTX-U, a major experiment in nuclear fusion being conducted at the Princeton Plasma Physics Laboratory.

Running a fusion reactor is like holding part of the sun in a bottle – its heart is a raging storm of particles trapped in a magnetic field.

To translate this storm's power into a practical energy source, scientists will have to harness and control the reactor by adjusting the twists and flows of its superheated particles.

"Plasma can destabilize in milliseconds," said Egemen Kolemen '08, an assistant professor in mechanical and aerospace engineering and the Andlinger Center for Energy and the Environment. "To control the reaction, we need to react in the same timescale."

Kolemen is one of several Princeton engineers working with colleagues at the Princeton Plasma Physics Laboratory (PPPL), a U.S. Department of Energy lab administered by Princeton University, to solve critical problems in making fusion energy a practical reality. In particular, Kolemen and Clarence Rowley '95, a professor of mechanical and aerospace engineering, lead separate projects to control the behavior of a state of matter known as plasma.

Instant decisions

A fusion reactor starts by heating light atoms such as hydrogen gas far beyond the temper-

ature of the sun. At such temperatures, electrons fly free of their atoms, leaving a swirl of electrically charged particles called plasma. If engineers can arrange this plasma into just the proper configuration, the particles will slam into each other and fuse into new types of matter, releasing massive amounts of energy. Scientists have been able to do this for minutes at a time, but maintaining a stable reaction for a fusion power plant that needs months to years of operation is a different story. The plasma constantly seeks to fling itself apart. Even if operators prevent this, they still have to control the plasma's constant twists and swirls to maximize the collisions among particles.

To make things more complex, there is no easy way to take real-time measurements of plasma's configuration – observations are possible, but they take time to analyze. That is where Kolemen's work begins.

"We gather pieces of diagnostic measurements and quantify the uncertainty," he said. "We try to put all this information in physics models and figure out what the situation is in the reactor."

Kolemen is assembling algorithms that will evaluate measurements of the plasma and make rapid calculations that trigger minute shifts in the reactor. The goal is to create an automated system that reacts quickly enough to maintain stability within the plasma.

"You need to understand all of the diagnostics, analyze them with the physics, predict if there is going to be a disruption, and take action," he said.

It might sound impossible, but Kolemen said the framework of the system is in place. He said engineers are now working to build up the system and increase its reliability.

"Making something so it works once in a while is easy," he said. "Going from a system that is functional for 90 percent of the time to the more than 99.99 percent reliability needed for a fusion power plant – that requires a bit more thinking."

Finding flow

While Kolemen seeks tools to control plasmas as they change, Rowley is developing mathematical models that reveal why instabilities develop in the first place.

To an untrained eye, the plasma seems to twist and roll randomly, but Rowley said that underlying patterns often hide in a multitude of details.

"If you really want to understand what is going on, to get to the heart of the matter, you want to strip away those details," Rowley said. "Often, it's something simple."

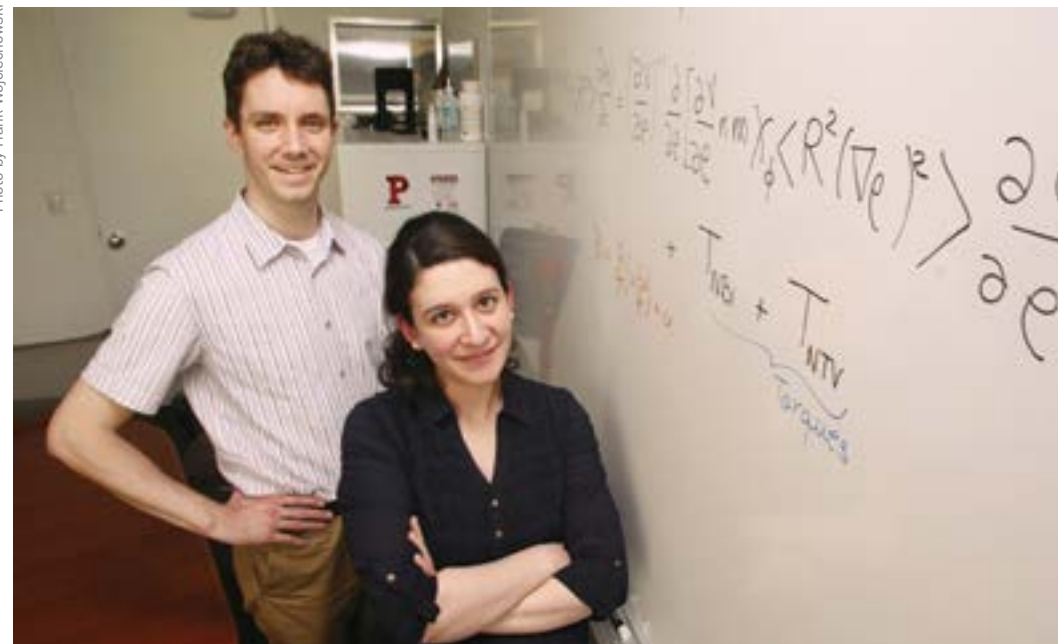
Imène Goumiri, a graduate student in Rowley's lab, recently worked with colleagues at Princeton and PPPL to develop a system using mathematical modeling and high-speed controls to reduce turbulence in plasmas created in the lab. Built on data from previous experiments, the program reacts quickly to changes in the plasma's flow and reduces instabilities by rotating sections of the plasma at different speeds.

Rowley's team has revealed how small changes that occur at critical locations and are amplified by other factors. The amplification can eventually cause the small change to play a big role in the overall flow.

"Trying to identify the features of the flow that are very sensitive to change is a big part of this business," Rowley said. "Even though this is about fluid dynamics or plasma, it can apply to any domain, which is why it is useful to think about it in a mathematical framework."

"For instance, if you are trying to understand instabilities in a power grid that could lead to blackouts, you want to know if there are places in the grid that are really vulnerable – if one generator went off, it could send ripples through the grid. These same techniques could give you a better understanding of that as well." **E**

Photo by Frank Wojciechowski



Clarence Rowley (left) and graduate student Imène Goumiri built on data from previous experiments in nuclear fusion to develop a method to reduce turbulence in the chaotic swarm of ultra-hot particles known as plasma, which is necessary for producing fusion power.

Photo by Noel Valero '82 *85



University President Christopher L. Eisgruber (left) awarded Presidential Teaching Awards to Professors Celeste Nelson (middle) and Brian Kernighan (right) at Commencement May 31.

Photo by Denise Applegate



Mung Chiang

'LIKE LEARNING PHYSICS FROM EINSTEIN' – STUDENTS LAUD TEACHERS

Five engineering professors were recognized for distinguished teaching at the 2016 graduation ceremonies.

Michael Celia *83, the Theodora Shelton Pitney Professor of Environmental Studies and professor of civil and environmental engineering, received the Graduate Mentoring Award. The director of the Program in Environmental Engineering and Water Resources, his research focuses on subsurface hydrology and energy systems, including carbon dioxide sequestration and shale gas. Students praised Celia's dedication. One student said that Celia "truly embodies what it means to be a mentor" and "will sit with you for no matter how long to go over problems and work them through with you step-by-step until you can explain it back to him."

Mung Chiang, the Arthur LeGrand Doty Professor of Electrical Engineering and director of the Keller Center, received the engineering school's Distinguished Teaching Award. His research uses mathematical analysis to strengthen and improve the design of wireless networks. In announcing the award, Yueh-Lin (Lynn) Loo *01, the engineering school's acting vice dean, noted that Chiang is known for his dedication to the craft of teaching. His undergraduate networking course is informally known as the "20 questions" class for the way he poses and helps students answer underlying questions about networks of various kinds. An online version of the course, "Networks: Friends, Money, and Bytes," has drawn more than 100,000 students since fall 2012.

Pablo Debenedetti, the Class of 1950 Professor in Engineering and Applied Science, received the Phi Beta Kappa teaching award. Debenedetti also serves as the University's dean for research. Seniors Kevin Silmore and Elizabeth Banes paid tribute to him as "a truly exceptional and inspiring teacher here at Princeton." Banes wrote in the citation for the

award, "Dean Debenedetti has made a name for himself as the kind, yet challenging lecturer of 'Introduction to Thermodynamics,' a pre-requisite course for all chemical and biological engineering majors." Banes also valued Debenedetti's qualities as a mentor to generations of Princeton students. "On weekdays, Dean Debenedetti will often be found holding personal office hours into the late evening, guiding any student in need of help through the complex web of thermodynamical concepts."

Brian Kernighan *69, a professor of computer science, received the Presidential Teaching Award. Kernighan is known for his ability to explain complex subjects. One colleague described the breadth of Kernighan's support of students: "Professor Brian Kernighan has distinguished himself as a master educator through his classroom teaching, his independent work-advising, his academic advising, his mentoring, and his outreach to the community of Princeton students. A legend in the computing field long before his arrival at Princeton, Brian leaves an indelible mark on every student he advises, teaches, and mentors." One undergraduate said "learning how to program from Brian Kernighan is like learning physics from Albert Einstein or calculus from Isaac Newton."

Celeste Nelson, a professor of chemical and biological engineering and director of the Program in Engineering Biology, received the Presidential Teaching Award. Colleagues underscored Nelson's talent in teaching and developing classes, including "Quantitative Physiology and Tissue Design" and "Physical Basis of Human Disease." A colleague noted that Nelson's ability to make connections across disciplines was demonstrated by the molecular biology department's invitation for her to teach its "Quantitative Principles in Cell and Molecular Biology" course. One recent graduate said, "We thrived under her expert and thoughtful teaching."

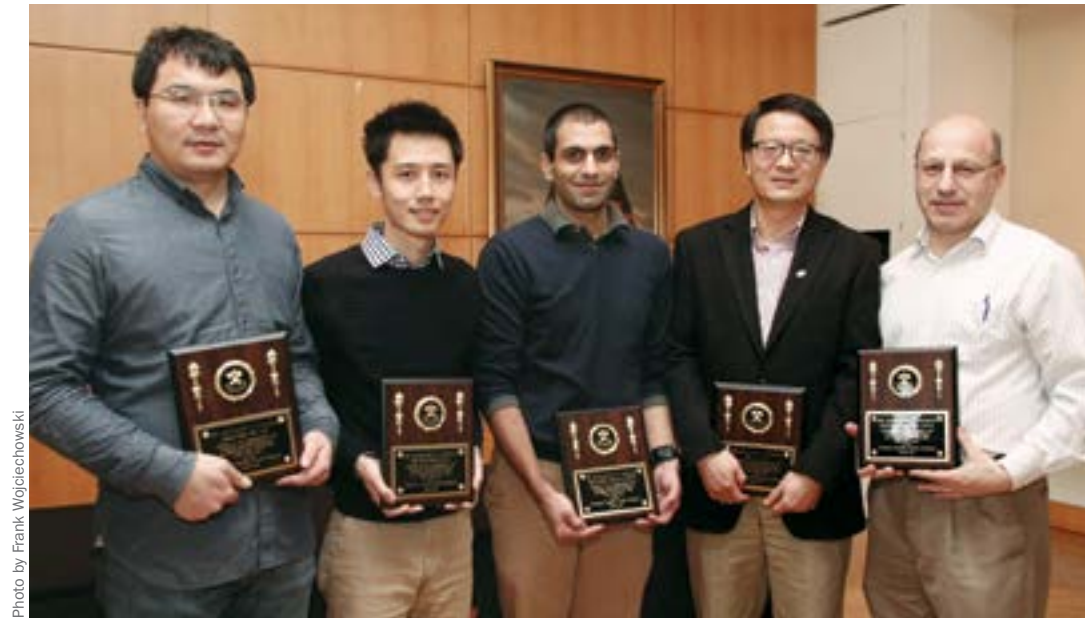


Photo by Frank Wojciechowski

CARTER AND CELIA ELECTED TO NATIONAL ACADEMY OF ENGINEERING

Two members of the engineering faculty, **Emily Carter** and **Michael Celia** *83, have been elected to the National Academy of Engineering, one of the highest professional honors for American engineers.

Carter, the dean of engineering and the Gerhard R. Andlinger Professor in Energy and the Environment, was recognized by the academy for "the development of quantum-chemistry computational methods for the design of molecules and materials for sustainable energy."

The founding director of the University's Andlinger Center for Energy and the Environment, Carter is known for her pioneering work in theoretical and computational chemistry. Among many professional honors, in 2008 Carter was elected to the National Academy of Sciences and the American Academy of Arts and Sciences. She also holds an appointment as professor of mechanical and aerospace engineering and applied and computational mathematics.

Celia, the Theodora Shelton Pitney Professor of Environmental Studies, was honored by the academy for "contributions to the development of subsurface flow and transport models in groundwater remediation and CO₂ sequestration."

His research focuses on modeling fluid flows in the subsurface with applications to groundwater flow, groundwater contamination, and subsurface energy systems, including studies of fluid migration in shale-gas systems. A fellow of the American Geophysical Union and the American Association for the Advancement of Science, Celia is the recipient of the 2005 AGU Hydrologic Sciences Award, and the 2014 Honorary Lifetime Membership Award from the International Society for Porous Media.

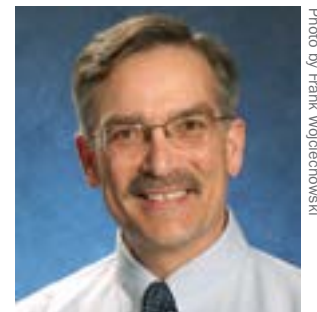
STUDENTS LAUD FACULTY FOR EXCELLENCE IN TEACHING

The undergraduate Engineering Council and the Graduate Engineering Council annually elect professors to receive the groups' Excellence in Teaching Award. The recipients at the spring 2016 ceremony were, from left, Han Liu, Hansheng Diao, Naveen Verma, Nan Yao, and Howard Stone.



Emily Carter

Photo by David Kelly Crow



Michael Celia

Photo by Frank Wojciechowski

RECENT FACULTY AWARDS AND HONORS



José Avalos

CHEMICAL AND BIOLOGICAL ENGINEERING

José Avalos
Research Fellowship, Alfred P. Sloan Foundation

Clifford Brangwynne
ASCB-Gibco Emerging Leader Prize, American Society for Cell Biology

Pablo Debenedetti
Fellow, American Physical Society

Yannis Kevrekidis
W.T. and Idalia Reid Prize, Society for Industrial and Applied Mathematics
Corresponding Member, Academy of Athens
Einstein Visiting Fellow, Einstein Foundation, Berlin
Rothschild Visiting Distinguished Fellow, University of Cambridge



Claire White

Yueh-Lin (Lynn) Loo *01
Finalist, Blavatnik National Award for Young Scientists
IDEAS Lab Moderator, World Economic Forum Annual Meeting of the New Champions



Maria Garlock

Celeste Nelson
College of Fellows, American Institute for Medical and Biological Engineering

CIVIL AND ENVIRONMENTAL ENGINEERING

Maria Garlock
T.R. Higgins Lectureship Award, American Institute of Steel Construction

Ning Lin *10
Howard B. Wentz Jr. Junior Faculty Award



Stephen Chou

Photos by Frank Wojciechowski unless otherwise indicated

Catherine Peters
Fellow, Association of Environmental Engineering and Science Professors

Claire White
CAREER Award, National Science Foundation

Eric Wood
Highly Cited Researcher, Thomson Reuters

COMPUTER SCIENCE

Mark Braverman
Presburger Award, European Association for Theoretical Computer Science

Barbara Engelhardt
Research Fellowship, Alfred P. Sloan Foundation
E. Lawrence Keyes Jr./Emerson Electric Co. Faculty Advancement Award

Jennifer Rexford '91
Athena Lecturer, Association for Computing Machinery, Council on Women in Computing
Best Paper Award, Association for Computing Machinery, Symposium on SDN Research

Robert Tarjan
Honorary Doctor of Mathematics, University of Waterloo

David Walker
Best Paper Award, Association for Computing Machinery, Symposium on SDN Research
Robin Milner Young Researcher Award, Association of Computing Machinery, Special Interest Group on Programming Languages

ELECTRICAL ENGINEERING
Emmanuel Abbe
CAREER Award, National Science Foundation
Google Faculty Research Award

Stephen Chou
Nanoimprint Pioneer Award, 14th International Conference on Nanoimprint and Nanoprint Technology

Claire Gmachl
Walter Curtis Johnson Prize for Teaching Excellence

Antoine Kahn *78
Fellow, School of Engineering, University of Tokyo

Prateek Mittal
CAREER Award, National Science Foundation
Cisco Faculty Research Award
Google Faculty Research Award

H. Vincent Poor *77
Fellow, World Academy of Sciences
Fellow, National Academy of Inventors
Fritz Medal, American Association of Engineering Societies
Highly Cited Researcher, Thomson Reuters

Barry Rand *07
Young Faculty Award, DARPA Young Investigator Award, Office of Naval Research

Alejandro Rodriguez
E. Lawrence Keyes Jr./Emerson Electric Co. Faculty Advancement Award

Sergio Verdu
Award for Scientific Reviewing, National Academy of Sciences



Jennifer Rexford

Sigurd Wagner
IBM Faculty Award

Gerard Wysocki
Best Paper Award, Japanese Symposium on Combustion

MECHANICAL AND AEROSPACE ENGINEERING
Emily Carter
Fred Kavli Innovations in Chemistry Lecturer, American Chemical Society

Marcus Hultmark *11
Young Investigator Award, U.S. Air Force

Yiguang Ju
Best Paper Award, Japanese Symposium on Combustion

Egemen Kolemen *08
Torkil Jensen Award, General Atomics/U.S. Department of Energy

Chung K. (Ed) Law
Highly Cited Researcher, Thomson Reuters

Naomi Ehrich Leonard '85
Innovation Hall of Fame, A. James Clark School of Engineering, University of Maryland

Michael Muller
Alfred Rheinstein Faculty Award

Photos by Frank Wojciechowski unless otherwise indicated

OPERATIONS RESEARCH AND FINANCIAL ENGINEERING

Amir Ali Ahmadi
CAREER Award, National Science Foundation
Best SICON Paper Prize, Society for Industrial and Applied Mathematics
Google Faculty Research Award
U.S. Junior Oberwolfach Fellow, National Science Foundation
Howard B. Wentz Jr. Junior Faculty Award



Emmanuel Abbe

Han Liu
Tweedie New Researcher Award, Institute of Mathematical Statistics



Egemen Kolemen

ARNOLD LEADS MATERIALS INSTITUTE

Craig Arnold, professor of mechanical and aerospace engineering, was appointed director of the Princeton Institute for the Science and Technology of Materials (PRISM) as of January 1. He had served as interim director since July 2015 when James Sturm, the Stephen R. Forrest Professor of Electrical Engineering, stepped down after 18 years leading the institute and earlier materials-science initiatives.



Arnold's research ranges from fundamental science to applied technology with a focus on materials synthesis and processing. He has particular interests in energy storage systems, laser materials processing, and advanced optics. Arnold co-founded TAG Optics, a company that uses technology developed in Arnold's lab for ultra-fast focusing lenses.

LOO TAKES HELM AT ANDLINGER CENTER

Yueh-Lin (Lynn) Loo *01, the Theodora D. '78 and William H. Walton III '74 Professor in Engineering and professor of chemical and biological engineering became director of the Andlinger Center of Energy and the Environment on July 1. She succeeded Founding Director Emily Carter, who is now dean of engineering.



A leader in organic and plastic electronics, Loo researches the development and processing of materials for low-cost, lightweight, and flexible solar cells and circuits. In recent work, Loo's group developed transparent solar cells to power technology that changes a material's color in response to electrical signals. Such "smart" windows will decrease energy use associated with the heating, cooling, and lighting needs of buildings.

PARTNERSHIPS YIELD GLOBAL IMPACT FOR ENGINEERS WITHOUT BORDERS

When Josh Umansky-Castro joined Engineers Without Borders (EWB) as a freshman, he traveled to the remote mountain town of La Pitajaya, Peru, to help build and maintain two water distribution systems serving 21 families.

The pipe systems that carry water downhill from a distant spring were designed by Princetonians who came before him, and who left a lasting impact on the mountain community.

Now a rising senior in mechanical and aerospace engineering, Umansky-Castro is making his own mark.

As one of two project managers for a new project in Pusunchás, Peru, his team is building a water system that will serve 120 families and provide over 6,300 gallons of running water per day. Each household is expected to have its own tap, a goal that local

Photo by Josh Umansky-Castro



The Princeton University chapter of the service group Engineers Without Borders received national recognition for its effectiveness in executing an expanding set of projects to provide clean water to communities in Africa and South and Central America. Above, students joined with community members in the summer of 2014 to dig a trench near La Pitajaya, Peru.

residents have strived for in the last 20 years.

“People have called us crazy,” Umansky-Castro said. “It’s going to be a lot of trenching.”

It’s the sort of dedication that has earned national recognition for the Princeton chapter. Among nearly 300 Engineers Without Borders programs in the United States, Princeton’s was honored at the EWB-USA International Summit in Denver this year with the organization’s Premier National Chapter Award. The Princeton team also received the Premier Chapter Award for the Northeast earlier this year.

The award recognizes a range of initiatives. In addition to the Peruvian pipeline, Princeton’s EWB program is designing and building rainwater catchment systems – which transfer rainwater from a building’s roof into a water tank through pipes – in the Dominican Republic and in Kenya.

“It’s pretty incredible when you think of the scale of EWB nationwide,” said Lucy Tang, a mechanical and aerospace engineering major and co-president of Princeton EWB. “The actual outcomes of the projects have been palpable for local people. Our students go out and do tough work.”

Tang’s co-president, Brendan Hung, an operations research and financial engineering major, said that the Princeton chapter develops strong relationships with the communities they serve, focusing on sustainability and regional needs.

“We are a successful chapter in balancing multiple programs, and we make sure to develop meaningful projects,” Hung said.

Umansky-Castro acknowledged that the new project in Pusunchás presents challenges on a larger scale than ever before, but said he is confident that the knowledge passed on from former EWB generations will help his team come through.

“EWB has redefined my perception of what college students are capable of,” Umansky-Castro said. –**Anna Windemuth ’17**

CLASS DAY AWARDS HONOR RESEARCH CONTRIBUTIONS AND SERVICE

The Princeton Class of 2016 included a record number of engineering students: One quarter of the class, or 317 students, earned BSE degrees, 37 percent of whom were women. Their plans for next year include graduate school at universities such as Massachusetts Institute of Technology, Harvard, and Oxford; government service; professional sports, including the National Football League; working at companies such as Merck, Microsoft, Google, Facebook, and some of the students’ own startups; and military service. At Class Day ceremonies May 30, the School of Engineering and Applied Science presented the following awards:

J. Rich Steers Award

Stephen O’Neill

Chemical and Biological Engineering

Eric Principato

Mechanical and Aerospace Engineering

Jeffrey O. Kephart ’80 Prize

Aditya Trivedi

Physics

Tau Beta Pi Prize

James Evans

Computer Science

Xiaoyan Han

Operations Research and Financial Engineering

Joseph Clifton Elgin Prize

Pelin Asa

Civil and Environmental Engineering

Stacey Huang

Electrical Engineering

George J. Mueller Award

Isaiah Brown

Operations Research and Financial Engineering

Calvin Dodd MacCracken Senior Thesis/Project Award

Sarah Cen

Mechanical and Aerospace Engineering

Zachary Schiffer

Chemical and Biological Engineering



Outgoing dean of engineering H. Vincent Poor (right) awarded prizes for scholarship and service at Class Day ceremonies May 30. Top row: Stephen O’Neill, Zachary Schiffer, Eric Principato, Riley Fitzgerald, Isaiah Brown. Middle row: Xiaoyan Han, Matthew Matl, Aditya Trivedi, James Evans, Matthew Volpe, Sarah Cen. Front row: Jason Altschuler, Stacey Huang, Pelin Asa.

Lore Von Jaskowsky

Memorial Prize

Riley Fitzgerald

Mechanical and Aerospace Engineering

Matthew Volpe

Chemical and Biological Engineering

James Hayes-Edgar Palmer

Prize in Engineering

Jason Altschuler

Computer Science

Matthew Matl

Electrical Engineering

Photo by Noel Valero '82 *85

Photos by David Kelly Crow



In a collaboration between electrical and civil engineers, students designed a flexible sensing sheet to warn engineers of weakness in bridges and other structures.

SENIOR THESIS LEADS TO CONCRETE RESULTS

When two Princeton engineering students set their minds to solving a tough technical problem for their senior theses this year, the results were concrete – or at least applicable to concrete.

“The objective was to develop a sensor sheet to detect strains over large areas of structures,” said Matthew Gerber ’16. He said the ultimate goal was to protect structures such as skyscrapers and dams by detecting “cracking, yielding, warping, anything significant beyond everyday normal use.”

James Sturm ’79, an electrical engineering professor who was one of the students’ advisers, said engineers have been pursuing a large-area sensor to monitor strain on the surfaces of buildings, bridges, and airplane wings for years. But so far the best sensors measure along a one-dimensional line rather than a two-dimensional surface.

“We sought a sheet of sensors to cover the surface,” said Sturm, the Stephen R.

Forrest Professor of Electrical Engineering. “We did some fundamental work on an approach several years ago, but had had little progress translating the electrical engineering end of it into a practical way forward.”

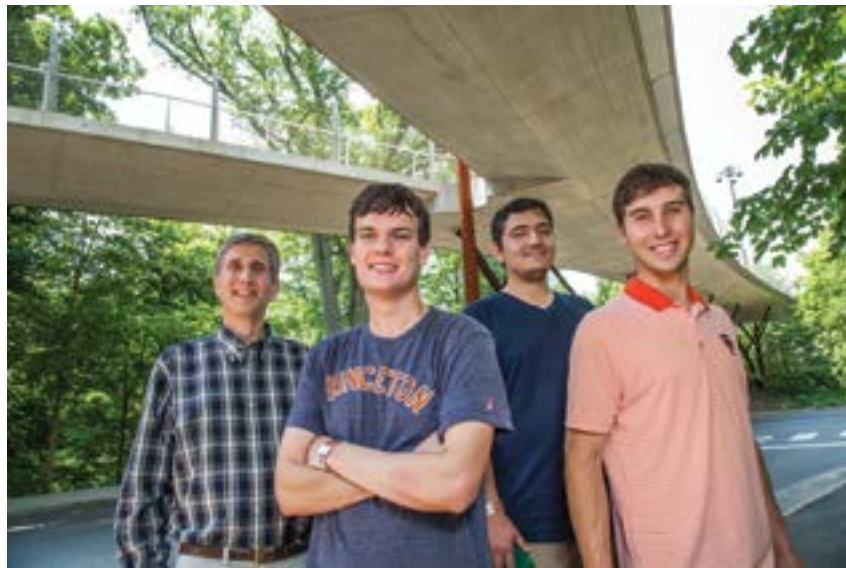
Campbell Weaver ’16 had been looking for a thesis idea with a practical impact, so Sturm suggested he explore ways to revive the wide-area sensor problem. Weaver quickly focused on two concerns: The electronics within the sensing sheets seemed overly complicated, and there was no reliable way to attach the sheet to a surface.

The project grew to include a multidisciplinary team: In addition to Sturm, Branko Glišić, an associate professor of civil and environmental engineering, had already been working on a similar sensing problem. Gerber, one of Glišić’s students, joined with Weaver to work on the adhesive problem. Other electrical engineering colleagues with expertise in sensors and flexible electronics joined as advisers: Associate Professor Naveen Verma, Professor Emeritus Sigurd Wagner, and post-doctoral researcher Levent Aygun.

Weaver devised a method to split the electronics into two units: the bare minimum needed in the sensing sheet and all the rest on a separate rigid circuit board. Meanwhile Gerber’s extensive tests of adhesives led to a particular product that was strong yet flexible.

Weaver and Gerber ultimately developed a system that they successfully deployed on the University’s Streicker Bridge. Aygun, who is continuing the research and did some of the early work along with a summer intern Juan Manuel, said recent results from the system have been very successful.

“What came out in the end is something we have sought for about four years,” Sturm said. “The work is of both fundamental and practical importance.” –JS



From left, Professor James Sturm, Campbell Weaver, Levent Aygun, and Matthew Gerber teamed up to develop the new sensor.



Photo by Frank Wojciechowski

GRADUATE STUDENTS CELEBRATED FOR EXCELLENCE IN TEACHING

The Princeton University Graduate School presented two graduate students in engineering with its annual Teaching Awards in recognition of their outstanding abilities as teachers. **Georgina Hall** from the Department of Operations Research and Financial Engineering and **Akil Word-Daniels** from the Department of Electrical Engineering were among this year’s nine recipients campus-wide.

Hall, a fourth-year graduate student, served as a teaching assistant for “Computing and Optimization for the Physical and Social Sciences,” “Convex and Conic Optimization,” and “Probability and Stochastic Systems,” which had more than 200 students. In one semester, she eagerly helped teach two courses at once. Assistant Professor Amir Ali Ahamdi, who co-taught with Hall for four semesters, wrote: “She simply shined in both courses. And she won a teaching award from the Engineering Council for her performance in ORF 309.” Professor Emeritus Erhan Çinlar added: “Georgina was one of the great teaching assistants. Her precepts were well

attended, her grading was impeccable, and she was appreciated by the students for her ability to explain difficult matters of logic and analysis. Ever since, she was every faculty member’s first choice for a teaching assistant.”

Word-Daniels, a third-year graduate student, served as a teaching assistant for “Electronic and Photonic Devices.” In her nomination, Claire Gmachl, the Eugene Higgins Professor of Electrical Engineering, described Word-Daniel’s efforts: “It was Akil who proposed and took upon himself to rework the Silicon Lab ... to give all students the very best lab experience. Akil designed a new lab project, taught it to his fellow A.I.s [teaching assistants], and guided 50 students through it; he did so on his own account and at significant extra workload for himself.” Gmachl continued: “Akil made a real, positive, and lasting difference for the students in ELE 208.” One student commented, “Best Lab TA ever.” And another added, “He was engaging and funny, but also dedicated to making sure everyone understood what was going on.” –JS

Graduate students (from left) Nana Kobby Aboagye, Akil Word-Daniels, Kevin Sallah, and Naima Hammoud received Excellence in Teaching Awards from the University’s Engineering Council and Graduate Engineering Council, which are the undergraduate and graduate student organizations of the School of Engineering and Applied Science.

Photo by Sameer Khan/Fotobuddy



Georgina Hall

Photo by Sameer Khan/Fotobuddy



Akil Word-Daniels

**GRADUATE RESEARCH
SPANS FUNDAMENTAL
DISCOVERY AND
PRACTICAL SOLUTIONS**

Graduates students at Princeton Engineering work at the intersection of fundamental science and practical, creative solutions. Here are just a few examples of students delving deep into chemical, physical, technological, and mathematical problems – all with an aim to addressing societal needs such as food security, health, environmental protection, and robust computer and financial systems.



WILL MULHEARN

**CHEMICAL AND BIOLOGICAL
ENGINEERING**

Hometown:

West Chester, Pennsylvania

Research:

Mulhearn is working to improve the resilience of polyethylene plastic under stress. On its own, polyethylene has desirable toughness because it partially crystallizes at room temperature. (This is why polyethylene milk bottles look cloudy.) Mulhearn seeks to dramatically improve the resistance of items made of polyethylene to deformation by the introduction of a second, highly inflexible polymer that can act as a support for the crystal domains. These hybrid materials are called block copolymers, in which a long, chain-like molecule of polyethylene is bonded to a second chain of a chemically different polymer.

Recent honor:

First place in the Journal of Polymer Science poster competition.



STEPHANIE DEBATS

**CIVIL AND ENVIRONMENTAL
ENGINEERING**

Hometown:

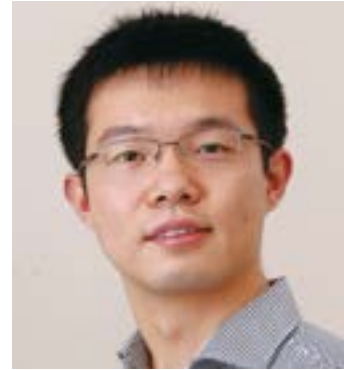
Irvine, California

Research:

Debats develops computer vision and machine-learning algorithms to analyze satellite imagery and detect the types of plants that cover the Earth's surface. She focuses on identifying subsistence agriculture in Sub-Saharan Africa, a region that typically has few sources of data for analyzing agricultural practices. By efficiently extracting vast feature sets for millions of image pixels, she trains computer algorithms to accurately identify the subtle patterns that define subsistence agriculture. The resulting data can be used to improve models that predict food insecurity hotspots, as well as track land-cover changes in the developing world.

Recent honors:

NASA Student Research Initiative Grant; Mary and Randall Hack '69 Graduate Award in support of innovative research on water and water-related topics.



XIN JIN

COMPUTER SCIENCE

Hometown:

Hangzhou, China

Research:

Jin designs and builds platforms for the management of computer networks. Network management is a long-standing problem, since network operators have to continuously update network configurations to alleviate congestion, detect and block cyber-attacks, and more. These updates are painful because operators have to balance the tradeoff between the disruption caused by the problem (e.g., congestion and cyber-attacks), and the disruption introduced by fixing the problem. Jin designs elegant, general solutions for transitioning a network from one configuration to another, and builds real systems to evaluate the solutions in practical settings.

Recent honors:

Princeton University's Procter Fellowship; Siebel Foundation Scholar.



MEI CHAI ZHENG

ELECTRICAL ENGINEERING

Hometown:

Brooklyn, New York

Research:

Zheng's research contributes to the development and improvement of devices that sense minute traces of gas for environmental monitoring and medical diagnostics. She works specifically on "quantum cascade" lasers that emit mid-infrared (mid-IR) light to enable more sensitive, compact and affordable sensors. Recently, she created a powerful device that enabled the development of a 3-D sensing and imaging platform, where the mid-IR light emitter not only provides the spectral data for sensing, but also the spatial data for 3-D imaging. Such a hyperspectral imaging system could provide patients with fast and non-invasive biomedical diagnostics without the need for biopsies.

Recent honors:

Harold W. Dodds Fellowship; 2015 Newport Graduate Award for Photonics.



KATIE FITCH

**MECHANICAL AND AEROSPACE
ENGINEERING**

Hometown:

Hamburg, New York

Research:

Fitch's research studies the dynamics and control of multi-agent networked systems such as mobile sensor networks or multi-agent robotic systems. Specifically, she focuses on the underlying graph structure of the networked system, identifying properties of influential sets of nodes. Her work has led to the definition of "joint centrality," a new notion that is key to maximizing a network's robustness to noisy inputs. She also studies which sets of nodes will be able to optimally control the network. Her research demonstrates a fundamental tension in terms of graph properties between the node sets that maximize robustness and those that optimize controllability.

Recent honors:

Larisse Rosentweig Klein Memorial Award; Wu Prize for Academic Excellence.



NANA KOBAYASHI

**OPERATIONS RESEARCH AND
FINANCIAL ENGINEERING**

Hometown:

Accra, Ghana

Research:

Aboagye works on developing an algorithm to test a finite number of possible responses to a problem with the aim of finding the action with the best performance metric. Examples of such a metric are financial revenue, efficacy of a chemical compound, test scores for a learning technique, and the number of clicks for an online ad. Choice of a particular action results in an observation, called the "reward," which is generated by some unknown underlying function called the "truth." Unlike previous iterations of this algorithm, Aboagye assumes that the truth for each alternative is transient and changing over time. Aboagye seeks to mathematically characterize the behavior of this algorithm.

Recent honor:

Engineering Council Excellence in Teaching Award.

Photos by Frank Wojciechowski

ALUMNI TAKE ON LEADERSHIP ROLES

Linda Abriola

The U.S. Department of State named **Linda Abriola** *83 as science envoy to develop partnerships, improve collaboration, and forge mutually beneficial relationships related to science and economic issues between the United States and other nations. A professor and former dean at Tufts University School of Engineering, Abriola also was named director of Tufts Institute of the Environment. Her Ph.D. is in civil engineering.



Diane Souvaine

Richard Benson '73 was appointed president of the University of Texas-Dallas effective July 15. Formerly dean of Virginia Tech's College of Engineering, Benson earned his BSE in mechanical and aerospace engineering at Princeton.



Ron Brachman

Ron Brachman '71 was appointed director of the Jacobs Technion-Cornell Institute in New York City. Formerly chief scientist at Yahoo and head of Yahoo Labs, Brachman earned his Princeton BSE in electrical engineering.

The TCP Group, a specialty chemical company in Houston, Texas, named **Edward Dineen** *78 as chairman, president, and chief executive officer. Dineen earned a master's in chemical engineering from Princeton.



Eric Schmidt

The National Institutes of Health named **Laura Forese** '83 as chair of its Clinical Center Hospital Board, a panel of external advisors. Forese, who earned her BSE in civil engineering, is the executive vice president and chief operating officer of New York Presbyterian health care system.



Alec Gallimore

Alec Gallimore *92 was named dean of engineering at the University of Michigan, where he succeeds David Munson*79, who had been dean for the last 10 years. Gallimore earned his Princeton Ph.D. in mechanical and aerospace engineering.

Lance Hack '83 has been named chief financial officer at Innovapptive, a mobile software developer in Houston, Texas. Hack earned his BSE in civil engineering.

Michael McCloskey '92 has been named chief financial officer at FusionHealth, a Suwanee, Georgia, company that provides technology to improve sleep and health across large populations. McCloskey earned his BSE in civil engineering and operations research.

James Soss '87 has been named executive vice president at YuMe, an advertising technology company that uses software to place ads across multiple video-viewing platforms. Soss earned his BSE in civil engineering.

Diane Souvaine *84 *86, vice provost for research at Tufts University, has been elected vice chair of the National Science Board, the governing body of the National Science Foundation. She earned her master's in electrical engineering and computer science and her Ph.D. in computer science.

Carl Sparks '89 recently became chief executive officer of Academic Partnerships, an online provider of technology-aided learning for non-profit universities. He earned his Princeton BSE in mechanical and aerospace engineering.

Eric Schmidt '76, executive chair of Alphabet, the parent company of Google, will head the Pentagon's new Defense Innovation Advisory Board formed to provide advice on technology and related innovation to U.S. Secretary of Defense Ash Carter. Schmidt earned his BSE in electrical engineering.



Frances Arnold

Frances Arnold '79, professor of chemical engineering and of bioengineering and biochemistry at the California Institute of Technology and director of the Rosen Bioengineering Center, has been awarded the 2016 Millennium Technology Prize from the Technology Academy of Finland. Arnold earned her Princeton BSE in mechanical and aerospace engineering.

Dan Boneh *96, **Mort Collins** *63 and **Thomas Connelly** '74 were elected to the National Academy of Engineering. Boneh, a professor of computer science at Stanford University, earned his Ph.D. in computer science at Princeton and serves on the department's Advisory Council. Collins, founder of MCollins Ventures LLC and member of the Princeton Engineering Leadership Council, earned his Ph.D. from Princeton in chemical engineering. Connelly is executive director and CEO of the American Chemical Society and holds a BSE in chemical engineering and an A.B. in economics from Princeton.

Charles A. Bouman Jr. *89 and **Norman Wagner III** *89 were elected to the National Academy of Inventors. Bouman, the Showalter Professor of Electrical and Computer Engineering and Biomedical Engineering at Purdue University, earned his Ph.D. from Princeton in electrical engineering. Wagner, the Robert L. Pigford Chaired Professor in the Department of Chemical and Biomolecular Engineering and

director of the Center for Neutron Science at the University of Delaware, earned his doctorate in chemical engineering at Princeton.

G. David Forney '61, received the IEEE Medal of Honor, the highest honor of the professional society of electrical engineers. Forney, an adjunct professor at Massachusetts Institute of Technology following a career in leadership at Codex Corp. and then Motorola, earned his BSE at Princeton in electrical engineering.

Cato Laurencin '80 received the National Medal of Technology and Innovation from President Barack Obama at a White House ceremony May 19. He was honored "for seminal work in the engineering of musculoskeletal tissues, especially for revolutionary achievements in the design of bone matrices and ligament regeneration; and for extraordinary work in promoting diversity and excellence in science." Laurencin, an orthopedic surgeon and professor at the University of Connecticut, earned his BSE from Princeton in chemical engineering.

Jackie Ying *91 was elected a fellow of the American Association for the Advancement of Science and of the Singapore National Academy of Science. She also received the Mustafa Prize, a top honor for scientists from nations within the Organization of Islamic Cooperation. Ying earned her Ph.D. in chemical engineering from Princeton.



Jackie Ying



Photo by NICHOLAS KAMM/APP/Getty Images

Cato Laurencin (left) of the University of Connecticut received the National Medal of Technology and Innovation from President Barack Obama at a White House ceremony May 19.