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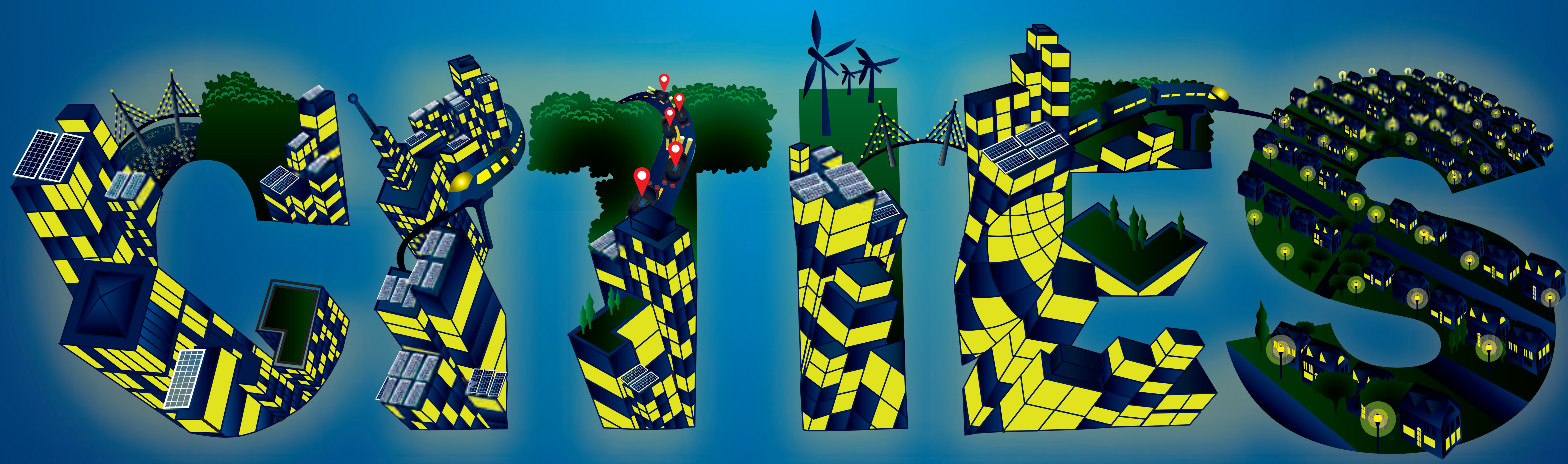

PRINCETON
School of Engineering
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Shaping Cities for People and the Planet

As Professor Elie Bou-Zeid eloquently explains on page 14 of this magazine, the way we build and reshape urban areas over the coming decades will determine a lot about the long-term health of society and this planet.

No small task, but Princeton excels at this kind of grand challenge. The future of cities is a complex mix of societal, technological, environmental, economic, and ethical questions, and Princeton is well equipped to knit creative, effective solutions. More generally, the Metropolis Project that Elie introduces is just one example of the high-impact work and focus on societal benefit at the School of Engineering and Applied Science. We have tremendous momentum and growth in data science, bioengineering, and robotics and cyber-physical systems, as well as in advancing the overall diversity and inclusion of the school.

Photo by Sameer A. Khan/Fotobuddy

All this work brings together two distinctive strengths of Princeton engineers: a culture of fluidly integrating diverse viewpoints and disciplines, and the ability to distill problems to their core constraints, then develop solutions with widespread impacts.

I welcome your comments, questions, and personal stories of engineering in the service of society.

H. Vincent Poor *77
Interim Dean
Michael Henry Strater University Professor of Electrical Engineering

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Photo by David Kelly Crow

Emily Carter

CARTER NAMED EXECUTIVE VICE CHANCELLOR AND PROVOST AT UCLA

Emily A. Carter, dean of Princeton University's School of Engineering and Applied Science, became the executive vice chancellor and provost of the University of California, Los Angeles, on Sept. 1, 2019.

H. Vincent Poor, the Michael Henry Strater University Professor of Electrical Engineering who served as dean from 2006 to 2016, is serving as interim dean as a search for Carter's successor proceeds.

Carter, who was the founding director of the Andlinger Center for Energy and the Environment for six years before becoming dean of engineering in July 2016, championed an important set of initiatives, including planning for a new campus neighborhood for engineering; a new first-year curriculum; growth of research and teaching in data science, bioengineering, robotics, and the future of cities; and multiple resources to strengthen diversity and inclusion across faculty, staff, and students.

"Emily Carter has made extraordinary contributions to Princeton as a scientist, mentor, center director, and dean," said Christopher L. Eisgruber, president of Princeton University. "She is a distinguished leader and brilliant scholar with heartfelt commitments to academic excellence, diversity, and the environment. Though we will miss having Emily as our colleague at Princeton, we look forward to applauding her accomplishments as she returns to UCLA."

At UCLA, where she was a faculty member for 16 years before joining the Princeton faculty in 2004, Carter serves as the university's second-ranking officer and as the chief operating and academic officer. The position calls for "bringing broad vision and executive leadership to campus-wide policy, planning, initiatives, and operations."

"Working with so many dedicated and extraordinarily talented colleagues at Princeton, as well as passionately supportive alumni, has been an honor and privilege," Carter said. "With their shared vision and momentum, the School of Engineering and Applied Science will continue to grow in serving humanity through innovation and generations of amazing students." **–Steven Schultz**

GIFT FROM ERIC AND WENDY SCHMIDT TO CREATE A NEW HOME FOR COMPUTER SCIENCE

Historic Guyot Hall will be substantially rebuilt and expanded to create a new home for Princeton's Department of Computer Science, thanks to a gift from Eric Schmidt '76 and his wife, Wendy Schmidt. Planned for completion in 2026, the building will be renamed as the Eric and Wendy Schmidt Hall and will consolidate the computer science department — which is currently spread out over nine different buildings — into one purpose-built space.

"Eric Schmidt's brilliant career as a computer scientist makes the Schmidt name especially fitting for the new home of Princeton's world-class Department of Computer Science," said President Christopher L. Eisgruber. "We are deeply grateful to Eric Schmidt '76, his wife, Wendy Schmidt, and Schmidt Futures for their spectacular vision and generosity. Their extraordinary commitments to this new facility, to the Schmidt DataX Fund, and to the Schmidt Transformative Technology Fund have powerfully enhanced Princeton's capacity for teaching, innovation, and collaboration that open new frontiers of learning and improve the world."

Earlier this year, the University announced the gift establishing the Schmidt DataX Fund, which will advance the breadth and depth of data science impact on campus, accelerate discovery in three large, interdisciplinary research efforts, and create opportunities to educate, train, convene, and support a broad data science community at the University. Additionally, in 2009 the Schmidts established the Eric and Wendy Schmidt Transformative Technology Fund, an endowment which supports the invention, development, and utilization of cutting-edge technology that has the capacity to transform research in the natural sciences and engineering at Princeton.

Eric Schmidt was formerly chief executive officer of Google from 2001 to 2011 and then served as executive chairman of Alphabet Inc, Google's parent company. He has also previously served as a trustee of the University. Wendy Schmidt is a businesswoman and philanthropist. She is the president of The Schmidt Family Foundation and co-founder of Schmidt Ocean Institute.

Eric Schmidt noted that when he earned his undergraduate degree from Princeton in 1976, "I majored in electrical engineering, because computer science was barely an option. Now it's the largest department at Princeton and data science has the potential to transform every discipline, and find solutions to profound societal problems. Wendy and I are excited to think about what will be possible when Princeton is able to gather students and faculty in one place, right at the center of campus, to discover now-unimaginable solutions for the future century."

Stu Feldman '68, Schmidt Futures chief scientist, said "Princeton University's computer science department is already one of the best in the world, and with this beautiful and larger purpose-built space, it is exciting to imagine how its stature will continue to grow."

Princeton's computer science department has grown to become the largest undergraduate major at the University, with approximately 25% of students majoring or earning a certificate in the discipline. Around 60% of undergraduates enroll in COS126, the introductory computer science course, and the University will have 44 tenure-track computer science faculty members in the fall semester of 2019. More than 36% of the department's undergraduate majors are women, about double the national average.

"Princeton recognizes that computational thinking as a mode of scholarship, inquiry, and critical thinking is essential across campus," said Jennifer Rexford '91, the Gordon S. Wu Professor of Engineering and chair of Princeton's computer science department. "We are deeply grateful for Eric and Wendy Schmidt's gift, which makes it possible to have a central location for computer science in which we can create intellectual collisions and serendipitous encounters between faculty and among students, creating human connections that spark new ideas across campus and beyond."

Guyot Hall was built in 1909, and was named for Princeton's first professor of geology and geography, Arnold Guyot, a member of the faculty from 1854 to 1884. The building's construction was supported with proceeds from gifts made to Princeton by Cleveland H. Dodge 1879 and his mother to benefit the University's programs in geology and biology.

Renovations will preserve the original collegiate Gothic architectural details of the building's exterior, and the Guyot name will be recognized in a new built space located elsewhere on campus which will be associated with Princeton's environmental science programs. The Schmidts' gift will come to Princeton from the Schwab Charitable Fund.

The renovation of Guyot Hall will increase the square feet assigned to the computer science department and will also build in capacity for future growth of the department's faculty and student body. During renovation of Guyot, the University will provide additional interim space in the Friend Center for the department. Construction is planned to begin in early 2024, with the computer science department projected to move into the renovated building in mid-2026.

Guyot Hall

Photo by Danielle Alio

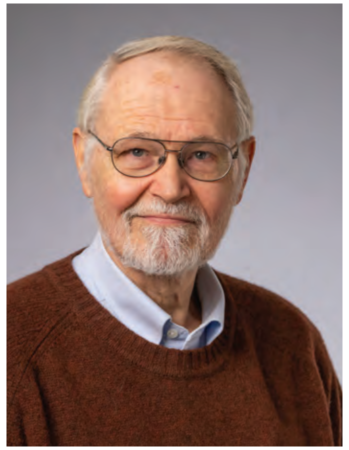
COMPUTER SCIENTIST KERNIGHAN *69 ELECTED TO AMERICAN ACADEMY OF ARTS AND SCIENCES

Brian Kernighan *69, a pioneer of early programming languages and software tools and a scholar known for distilling and clarifying complex technical subjects, has been elected to the American Academy of Arts and Sciences. A professor of computer science, Kernighan is among five Princeton faculty members, a visiting professor, and six alumni joining the academy this year.

Kernighan's work focuses on programming, software tools, application-oriented languages, and technology education. He is the author of a series of books that have become known for clarity and precision. Among them is "The C Programming Language" (Prentice Hall, 1978), written with Dennis Ritchie. The book, known among programmers as "K&R," is a fundamental text on the language. His most recent books include "Millions, Billions, Zillions" (Princeton University Press, 2018) and "Understanding the Digital World" (Princeton University Press, 2017).

Kernighan received his master's and doctoral degrees in electrical engineering from Princeton. He worked at Bell Labs for 30 years before joining the Princeton faculty in 2002. Among other honors, he is a recipient of the USENIX Association Lifetime Achievement Award and is a member of the National Academy of Engineering.

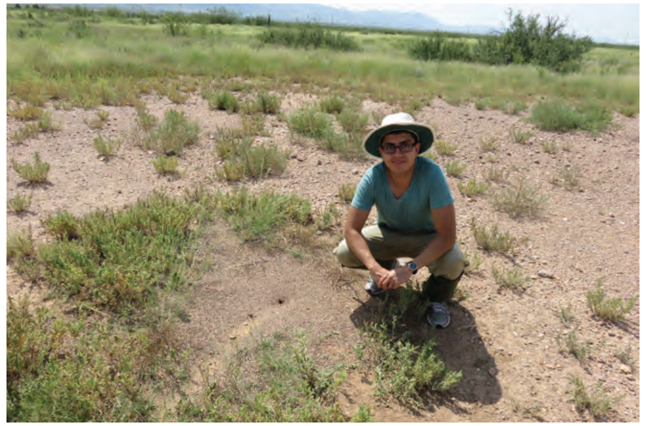
Photo by David Kelly Crow



Brian Kernighan *69

ANTS' SURVIVAL STRATEGY COULD AID LEADERLESS GROUP ROBOTICS

Ants' frenzied movements may seem aimless and erratic to a casual observer, but closer study reveals that an ant colony's collective behavior can help it thrive in a harsh environment — and may also yield inspiration for robotic systems.



Graduate student Renato Pagliara Vásquez spent part of two summers conducting field research on desert harvester ants in southern New Mexico.

Photo by Renato Pagliara Vásquez

In a new analysis, Princeton researchers created a mathematical model to explain how desert harvester ants collectively weigh the cost of losing water while foraging against the benefit of bringing in more food. The model is a tool for investigating how ant colonies respond to a changing environment, and how behavioral differences among colonies affect their long-term survival and reproductive success. The team published their results in the journal PLOS Computational Biology.

Professor Naomi Ehrich Leonard '85, the study's senior author, has previously analyzed the dynamics of bird flocks and fish schools to understand how large groups can operate efficiently without central control. Insights gained from these natural systems can help in the design of robot teams to carry out search and rescue missions or take measurements of environments inaccessible to humans. **–Molly Sharlach**

GOOGLE AI LAB BOLSTERS INNOVATION AND INVENTION

At an event to celebrate the opening of the Google AI Lab in Princeton, senior Abby Van Soest (center) presents her research poster to NJ Governor Phil Murphy (left) and Assemblyman Andrew Zwicker (right).

Two Princeton University computer science professors are leading a new Google AI lab that is located in the town of Princeton and which officially launched in May.

The lab, at 1 Palmer Square, is already playing a vital role in expanding New Jersey's innovation ecosystem by building a collaborative effort to advance research in artificial intelligence. The lab builds on several years of close collaboration between Google and professors of computer science Elad Hazan and Yoram Singer, who will split their time working for Google and Princeton. The work at the lab includes a small number of faculty members, graduate and undergraduate student researchers, recent graduates, and software engineers.

Photo by Denise Applewhite

"We are thrilled that Google is in Princeton," President Christopher L. Eisgruber said in celebrating the new lab at an event that was also attended by former chairman and executive CEO of Google Eric Schmidt '76 and New Jersey Governor Phil Murphy. "By bringing together talented researchers from Princeton and Google, and by giving them access to Google's exceptional computing resources, this collaboration promises to deepen our understanding of machine learning and produce exciting innovations," Eisgruber said.
–Liz Fuller-Wright

ARTIFICIAL INTELLIGENCE DETECTS A NEW CLASS OF MUTATIONS BEHIND AUTISM

Many mutations in DNA that contribute to disease are not in actual genes, but instead lie in the 99% of the genome once considered "junk." Even though scientists have recently come to understand that these vast stretches of DNA do in fact play critical roles, deciphering these effects on a wide scale has been impossible until now.

Using artificial intelligence, a Princeton-led team has decoded the functional impact of such mutations in people with autism. The researchers believe this powerful method is generally applicable to discovering such genetic contributions to any disease.

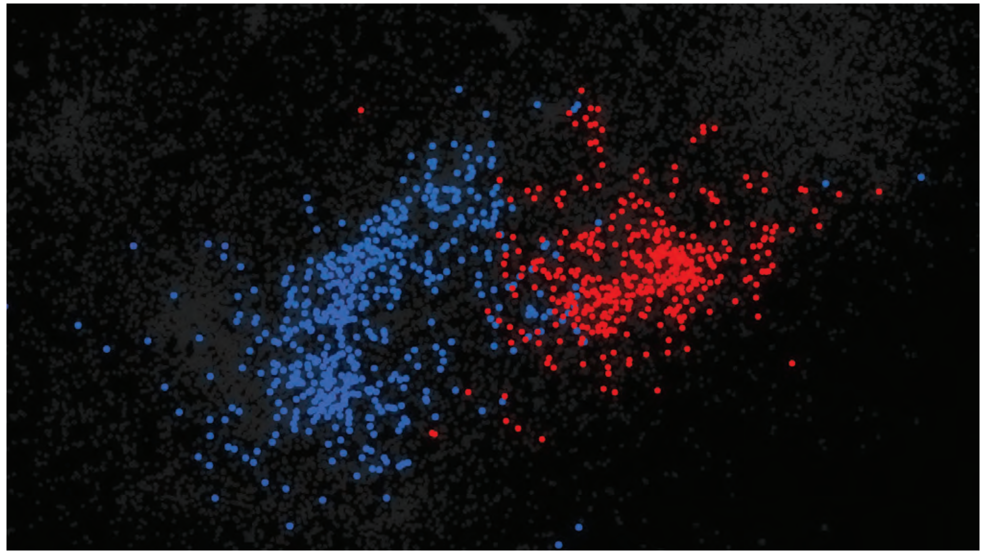
Publishing in the journal Nature Genetics, the researchers analyzed the genomes of 1,790 families in which one child has autism spectrum disorder but other members do not. The method sorted among 120,000 mutations to find those that affect the behavior of genes in people with autism. Although the results do not reveal exact causes of cases of autism, they reveal thousands of possible contributors for researchers to study.

Much previous research has focused on identifying mutations in genes themselves. Genes are essentially instructions for making the many proteins that build and control the body. Mutations in genes result in mutated proteins whose functions are disrupted. Other types of mutations, however, disrupt how genes are regulated. Mutations in these areas affect not what genes make, but when and how much they make.

Until now, it was not possible to look across the entire genome for snippets of DNA that regulate genes and predict how mutations in this regulatory DNA are likely to contribute to complex disease, the researchers said. This study is the first proof that mutations in regulatory DNA can cause a complex disease.

"This method provides a framework for doing this analysis with any disease," said Olga Troyanskaya, professor of computer science and genomics and a senior author of the study. The approach could be particularly helpful for neurological disorders, cancer, heart disease, and many other conditions that have eluded efforts to identify genetic causes.

"This transforms the way we need to think about the possible causes of those diseases," said Troyanskaya, who also is deputy director for genomics at the Simons Foundation's Flatiron Institute in New York, where she led a group of co-authors. **–Steven Schultz**



Genes predicted to be disrupted by regulatory mutations in people with autism tended to be involved in brain cell functioning and fell into two categories. One category (shown in blue) relates to synapses, communication hubs between neurons, and the other (shown in red) relates to chromatin, the highly structured form of DNA and proteins required for proper gene expression in chromosomes.

Image by Troyanskaya Lab/Neil Adelantar

SUNLIGHT PULLS HYDROGEN FROM WASTEWATER

Hydrogen is a critical component in the manufacture of thousands of common products from plastic to fertilizers, but producing pure hydrogen is expensive and energy intensive. Now, a research team at Princeton has harnessed sunlight to isolate hydrogen from industrial wastewater.

In a paper published in the journal Energy & Environmental Science, the researchers reported that their process doubled the currently accepted rate for scalable technologies that produce hydrogen by splitting water. The technique uses a specially designed chamber with a "Swiss cheese" black silicon interface to split water and isolate hydrogen gas. The process is aided by bacteria that generate electrical current when consuming organic matter in the wastewater; the current, in turn, aids the water-splitting process.

The team, led by Zhiyong (Jason) Ren, professor of civil and environmental engineering and the Andlinger Center for Energy and the Environment, chose wastewater from breweries for the test. They ran the wastewater through the chamber, used a lamp to simulate sunlight, and watched the organic compounds break down and the hydrogen bubble up.

The process "allows us to treat wastewater and simultaneously generate fuels," said Jing Gu, a co-researcher and assistant professor of chemistry and biochemistry at San Diego State University.

The researchers said the technology could appeal to refineries and chemical plants, which typically produce their own hydrogen from fossil fuels, and face high costs for cleaning wastewater.

Historically, hydrogen production has relied on oil, gas, or coal, and an energy-intensive method that involves processing the hydrocarbon stock with steam. Chemical manufacturers then combine the hydrogen gas with carbon or nitrogen to create high-value chemicals, such as methanol and ammonia. The two are ingredients in synthetic fibers, fertilizer, plastics, and cleaning products, among other everyday goods.

Although hydrogen can be used as a vehicle fuel, the chemical industry is currently the largest producer and consumer of hydrogen. Producing chemicals in highly industrialized countries requires more energy than producing iron, steel, metals, and food, according to a 2016 report from the U.S. Energy Information Administration. The report estimates that producing basic chemicals will continue to be the top industrial consumer of energy over the next two decades.

"It's a win-win situation for chemical and other industries," said Lu Lu, the first author on the study and an associate research scholar at Princeton. "They can save on wastewater treatment and save on their energy use through this hydrogen-creation process." **–Molly Seltzer**

Researchers run the wastewater through a specially designed chamber, use a lamp to simulate sunlight, and watch the organic compounds in the waste break down and the hydrogen bubble up.

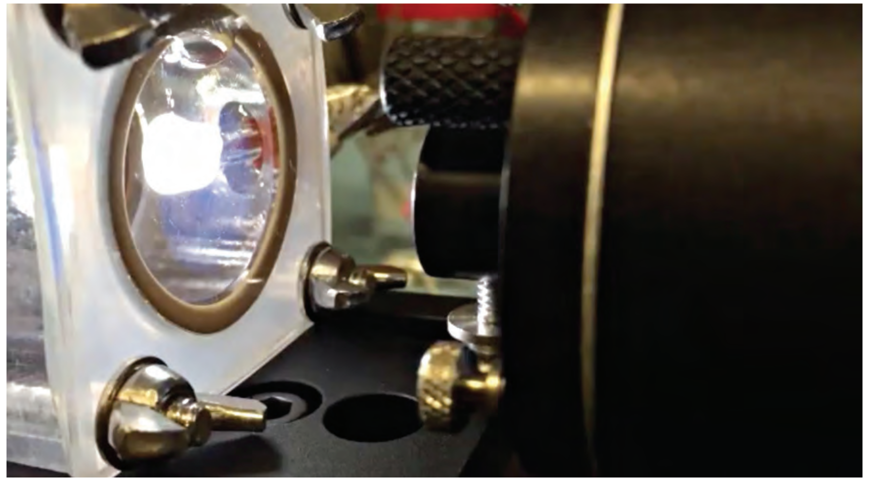


Photo by Bumper DeJesus

ALCATRAZ ISLAND IS UNLIKELY PLACE OF LEARNING FOR STUDENTS OF ENERGY INNOVATION

On Alcatraz Island, five students from Princeton University peered across the San Francisco skyline from a solar rooftop. Their visit to the historic prison's electricity microgrid was one stop on a spring break trip to see emerging energy technologies, part of a new course on energy innovation and entrepreneurship.

"Before this class I didn't even know what the energy sector looked like," said Diego Fierros, a senior studying mechanical and aerospace engineering. "It was a giant engineering conglomerate."

The trip took students to the front lines of Silicon Valley, from startups and incubators to multi-million-dollar solar and battery companies, including Tesla and SunRun, to see up close how entrepreneurs are commercializing new energy technologies.

On Alcatraz, the students saw the microgrid that powers the island, composed of solar panels and batteries. The ability to use solar energy to support most of the island's operations, despite periodic cloudiness and nightly darkness, reflects decades of improvements in battery cost and technology, said Darren Hammell '01, the president and CEO of Princeton Power Systems. Hammell taught the course as part of his tenure as a Gerhard R. Andlinger Visiting Fellow in Energy and the Environment.

Hammell had behind-the-scenes access to the Alcatraz power systems because his company built and deployed the island's microgrid. He founded Princeton Power Systems as an undergraduate at Princeton in 2001 and developed the course to bring a business and entrepreneurship perspective to students studying energy technologies.

"It's important for students to understand not just the engineering aspects of energy projects and technologies, but the policy and economic context," said Hammell. "They need to be able to assess potential applications, markets, and customers, and how a new innovation might be positioned within the existing industry."

Photo by Jana Ašenbrennerová

As part of the spring course "Energy Innovation and Entrepreneurship," students took an optional trip over spring break to Silicon Valley. The trip included a visit to Alcatraz across from San Francisco to learn about the microgrid that powers the island, composed of solar panels and batteries. From left to right, a Princeton Power Systems field operator and a National Park Service ranger stroll with Darren Hammell, CEO of Princeton Power Systems who teaches the course, and Princeton graduate student Isla (Xi) Han, along the rooftop of the historic prison on Alcatraz Island.

Through case studies on existing companies and via collaborative discussions and presentations on company business models, the students learned many factors that affect how a technology is scaled up. The trip allowed students to use that knowledge in conversations with company executives.

"We were able to ask them questions about why they made certain decisions," said Erin Redding, a senior in the Woodrow Wilson School of Public and International Affairs. "That was really cool to be able to go from a class project to actually applying that knowledge in conversations with a CEO of a startup." **–Molly Seltzer**

NEW TECHNOLOGY MARKS A KEY STEP TOWARD SHRINKING A MEDICAL LAB TO FIT ON FINGERTIP

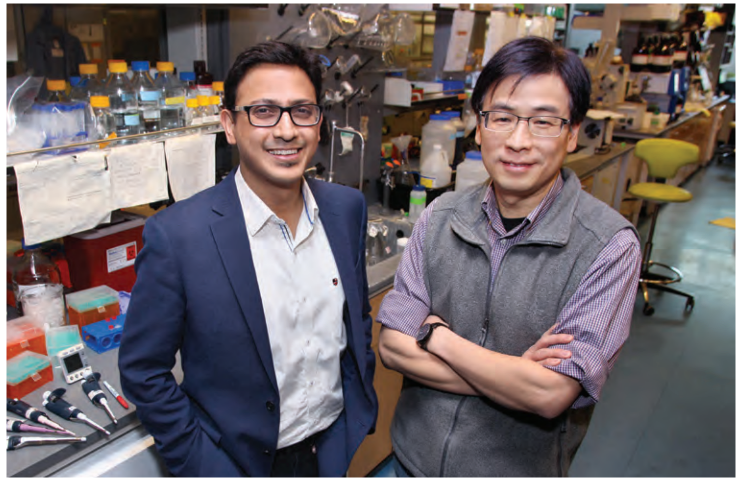


Photo by Frank Wojciechowski

From left: Kaushik Sengupta, assistant professor of electrical engineering, and Haw Yang, professor of chemistry, have developed sensor technology using standard microchips.

Identifying a patient's viral infection or diagnosing a blood disorder usually requires a lab and skilled technicians. Now researchers at Princeton University have developed a new technology that goes a long way toward replacing the lab with a single microchip.

The technology, described in articles in the journals ACS Photonics and Biomedical Optics Express, uses tiny metal layers embedded in a microchip to eliminate all complex and bulky optical instrumentation employed in diagnostic labs. As a result, the new system is almost as small as a grain of salt, and far less costly to manufacture than current diagnostic systems.

"The key idea is to allow complex optical systems in modern-day chips," said Kaushik Sengupta, an associate professor of electrical engineering and one of the project's leaders.

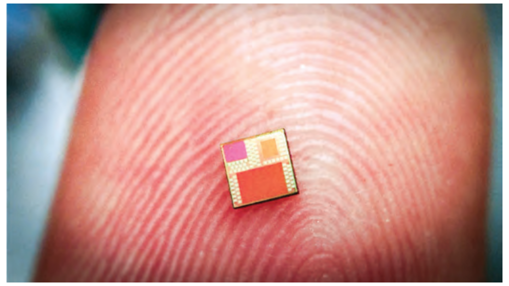


Photo by Lingyu Hong

Princeton researchers have created biosensors by adapting silicon chip technology similar to that found in personal computers and mobile phones. The technology uses tiny metal layers embedded in a microchip to eliminate all complex and bulky optical instrumentation employed in the diagnostic labs.

A commercial fluorescence-based biosensor typically carries an array of classical optical components including multiple filter sets, lenses, and gratings. The more sensitive the system is, the more expensive and bulky the setup.

The researchers found that tiny metal layers already built into modern microchips can relatively easily be adapted to take advantage of light's unusual behavior when interacting with structures smaller than a single wavelength of light. Harnessing the light in this way allows for detection of thousands of biological substances, from bacterial DNA to hormones. And because modern microchips already are designed to be extremely small, these structures can be made using standard manufacturing techniques, Sengupta said.

The new sensor chip, like a classic lab setup, detects targeted molecules by using chemical antibodies designed to react in the presence of a specific molecule. The antibodies are modified to generate light at a specific wavelength (fluoresce) when they are exposed to the target.

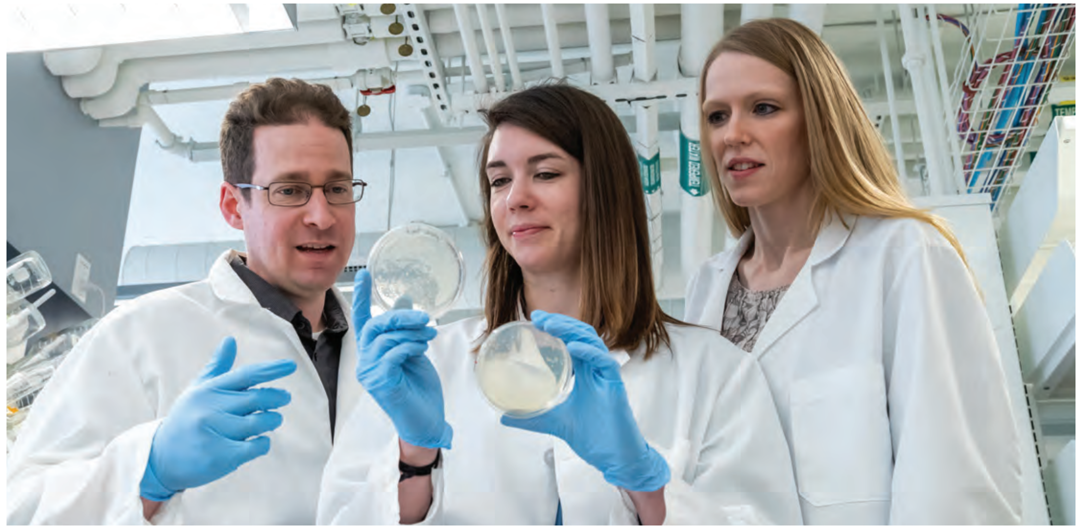
In a standard lab, the antibodies are placed in small wells on a testing plate about the size of a playing card. To make the assembly small enough to fit onto a chip measuring 4 millimeters per side, Sengupta and his group worked with the group led by Haw Yang, a chemistry professor, to develop new techniques to prepare and distribute the antibodies.

Although more work is required, the researchers hope the technology will lead to diagnostic systems contained in a pill or deployed on a smartphone.

"We show for the first time that this level of optical field manipulation is possible in a silicon chip. By eliminating all classical optics, the system is now small enough that you could start thinking about putting it in a pill," Sengupta said. **–Bennett McIntosh**

RESEARCH FINDS SOME BACTERIA TRAVEL ALTERNATE PATH TO ANTIBIOTIC RESISTANCE

Photo by David Kelly Crow



Princeton researchers have identified a new path that some bacteria take toward antibiotic resistance. The research team included (from left) Mark Brynildsen, associate professor of chemical and biological engineering; Allison Murawski, an M.D.-Ph.D. student; and Theresa Barrett *17, who recently completed her doctoral work in Brynildsen lab's and is finishing a medical degree at Rutgers Robert Wood Johnson Medical School in New Brunswick, New Jersey.

In a study with implications for efforts to halt the spread of antibiotic-resistant bacteria, researchers at Princeton have identified a new, troubling path that some bacteria take toward resistance.

The discovery focused on bacteria called persisters, which are different from antibiotic-resistant bacteria. Resistant bacteria possess genetic mutations that directly protect them against antibiotics. Persisters, on the other hand, while not genetically endowed with a better chance of survival than resistant mutants, can nevertheless tough it out because of certain genes they switch on or off before, during or after antibiotic treatment.

The new study, published in Nature Communications, found that the line between the two types of bacteria is not as clear as scientists previously thought. In fact, the researchers found that some persisters were more likely than standard bacteria to produce offspring with the direct, genetic-mutation resistance to antibiotics. More disturbingly, the researchers found, the persisters' offspring went on to exhibit resistance not only to the drug their forbearers had survived but also to completely different classes of antibiotics.

"Our study has demonstrated that persister bacteria can add substantially to the risk that antibiotic-resistant mutants will arise," said Mark Brynildsen, an associate professor of chemical and biological engineering at Princeton and the study's senior author. "We've known that because they survive the first wave of treatment, persisters can cause chronic infections. But their role in promoting drug resistance is an unexpected and troubling finding."

To help slow the emergence of lethal superbugs, clinicians and pharmacologists will need to adopt new therapeutic tactics against persisters. "Our study offers compelling data that when treating bacterial populations, we have to get rid of the persisters," said Brynildsen. **–Adam Hadhazy**

OPTIMIZING OPERATIONS FOR AN UNPRECEDENTED VIEW OF THE UNIVERSE

Under construction on a remote ridge in the Chilean Andes, the Large Synoptic Survey Telescope (LSST) will boast the world's largest digital camera, helping researchers detect objects at the solar system's edge and gain insights into the structure of our galaxy and the nature of dark energy.

This extraordinary power is attracting scores of researchers worldwide, each with their own observational needs and timescales and all contending with sporadic cloud cover and other variable conditions. In short, a major scheduling challenge.

An automated telescope scheduler developed by researchers at Princeton and the University of Washington aims to maximize the LSST's efficiency over the span of its operation, currently planned for 10 years beginning in 2023.

The team includes Elahesadat Naghib *19, who earned a Ph.D. in Princeton's Department of Operations Research and Financial Engineering, and Professor Robert Vanderbei.

The scheduler will collect real-time data on factors including cloud cover, sky brightness, and astronomical "seeing" — the amount of star twinkling caused by Earth's atmosphere, which can affect the resolution of telescope images. While cloud cover is relatively rare at the LSST site in the Atacama Desert, one of the driest places on Earth, clouds are still a concern for the telescope's operation.

At each moment of the night, these measurements will help a decision-making algorithm determine where in the sky the telescope should point and which filter it should use to capture an image. The LSST will use six filters that allow the transmission of different wavelengths of light, ranging from ultraviolet to near-infrared. The light spectra emitted by astronomical features such as supernovae, or exploding stars, can reveal key information about their origins and chemical composition.

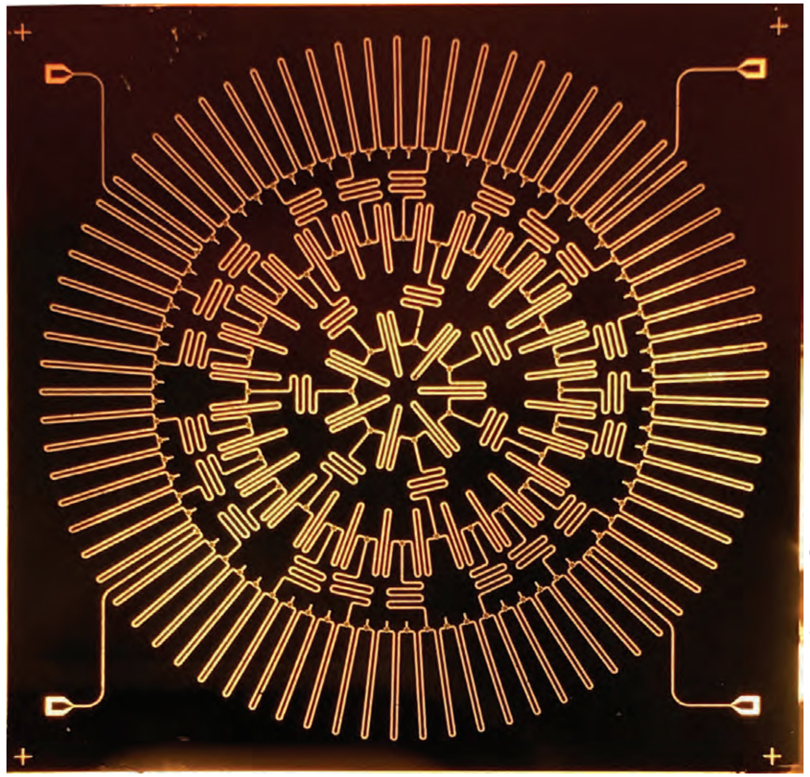
"Because we're making a real-time decision, the LSST can actually evaluate the clouds and be able to keep observing, whereas [with previous telescope algorithms] they would have to shut down the whole observatory when the night was cloudy," said Naghib.

In addition to accounting for weather and other variable conditions, the scheduler incorporates information about the length of time required for the telescope to rotate from one field of view to another. Optimizing the efficiency of these movements is particularly important for the LSST because it will change positions faster than previous telescopes, and therefore make more observations in a given time. Each night, the scheduler will prioritize points of the sky not observed during the previous night, enabling the telescope to observe the entire southern sky every three nights.

"One of the challenges in this project is that different regions of the sky have different constraints and different objectives, and we have to respect all of those based on what they require," explained Naghib, who spent a semester working with astronomers at the University of Washington to refine the scheduler's functions. **–Molly Sharlach**

The Large Synoptic Survey Telescope will boast the world's largest digital camera, helping researchers detect objects at the solar system's edge and gain insights into the structure of our galaxy and the nature of dark energy.

Photo by M. Park/Inigo Films/LSST/AURA/NSF



Images courtesy of the researchers

Princeton researchers have built an electronic array on a microchip that simulates particle interactions in a hyperbolic plane, a geometric surface in which space curves away from itself at every point.

STRANGE WARPING GEOMETRY HELPS TO PUSH SCIENTIFIC BOUNDARIES

Atomic interactions in everyday solids and liquids are so complex that some materials' properties continue to elude physicists' understanding. Solving the problems mathematically is beyond modern computers, so scientists at Princeton have turned to an unusual branch of geometry.

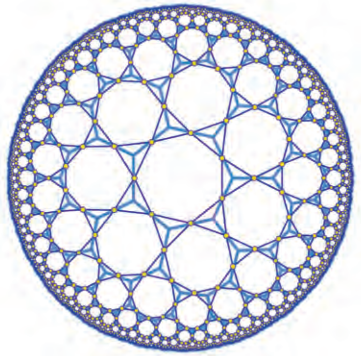
Researchers led by Andrew Houck '00, a professor of electrical engineering, built an electronic array on a microchip that simulates particle interactions in a hyperbolic plane, a geometric surface in which space curves away from itself at every point. It is difficult to envision — the artist M.C. Escher used hyperbolic geometry in many of his mind-bending pieces — but perfect for answering questions about quantum interactions, which govern the behavior of atomic and subatomic particles.

The researchers used superconducting circuits to create a lattice that functions as a hyperbolic space. By introducing photons into the lattice, researchers can answer a wide range of difficult questions by observing the photons' interactions.

"You can throw particles together, turn on a very controlled amount of interaction between them, and see the complexity emerge," said Houck.

Alicia Kollár '10, a postdoctoral research associate at the Princeton Center for Complex Materials and the lead author of the study published in Nature, said the goal is to allow researchers to address complex questions that are very difficult to solve with computer models.

"We're trying to implement a model at the hardware level so that nature does the hard part of the computation for you," Kollár said. **–Molly Sharlach**



A schematic of the resonators on the microchip, which are arranged in a lattice pattern of heptagons, or seven-sided polygons. The structure exists on a flat plane, but simulates the unusual geometry of a hyperbolic plane.

Photo by Ian Douglas

Excerpts from "There Might Be Others" premiered at New York Live Arts in March 2016. The performance was choreographed and directed by Rebecca Lazier in collaboration with the performers, with music by Dan Trueman in collaboration with Sō Percussion and Mobius Percussion. Video by Metin Çavuş. **https://vimeo.com/214109089**

IMPROVISED DANCE EMBODIES COMPLEXITIES OF SOCIAL DECISIONS

Princeton researchers developed a mathematical analysis of dancers' decisions in the rule-based improvisational work "There Might Be Others." The work is part of an ongoing effort to explore collective behavior in nature and art and to inform the design of control systems for robot teams.

Art evolves from decisions, as an artist combines brushstrokes, dance steps, or musical notes. When a dance group improvises from a repertoire of possible movements, the dynamics of the artistic decisions become even more complex.

A team led by Naomi Erhich Leonard '85 investigates collective behavior in nature and art to inform the design of control systems for robot teams operating in challenging environments.

Leonard, the Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering, is the senior author of a recent mathematical analysis of dancers' decisions and opportunities for collaborative composition in the rule-based improvisational work "There Might Be Others," choreographed by Rebecca Lazier, a senior lecturer in dance in the Lewis Center for the Arts. In the piece, dancers make sequential choices among 44 movement modules inspired by a variety of dance styles. Performance rules guide and constrain when, where, and how the dancers perform the sequence of modules. Professor of Music Dan Trueman *99 composed accompanying music that also relies on rules and improvisation.

"The dancers were incredible to work with," said Leonard. "They could express the way it made them feel when our manipulations of the rules gave them more ideas. We learned new ways in which we could impose constraints on the dancers that would make the art more challenging, and therefore more interesting and more exciting." **–Molly Sharlach**

CONFERENCE EMPHASIZES WIDE IMPACTS OF GROWING CITIES

Photo by Sameer A. Khan/Fotobuddy

Anu Ramaswami, a leading researcher on sustainable urban systems, spoke at the opening session of the Building the Future: New Technological Frontiers in Cities conference. Ramaswami joined the Princeton faculty on Aug. 1 as the inaugural director of the M.S. Chadha Center for Global India and professor of India studies, civil and environmental engineering, and the Princeton Environmental Institute.

Any attempt to address challenges of the future, from clean energy to a sufficient food supply, must grapple with the issues raised by the planet's rapidly growing cities, speakers said during a May 6 conference at Princeton.

"We believe that the future of cities is the future of the planet," Emily Carter, then dean of engineering, said in her opening address in the Friend Center lecture hall.

Emphasizing the New York-Philadelphia corridor's strong innovation ecosystem, the conference, called Building the Future: New Technological Frontiers in Cities, brought together representatives from academia, industry, and government to discuss research and policies. Princeton led coordination of the conference with Rutgers University, the College of New Jersey, the New Jersey Institute of Technology, and Stevens Institute of Technology. Twenty-three regional and national firms described technological innovations during a corporate session; and 16 city governments, state offices, and planning organizations highlighted municipal needs and issues. The conference also offered a panel discussion with three mayors moderated by Beth Simone Noveck, New Jersey's chief innovation officer.

The conference highlighted Princeton's new Metropolis Project, which supports research into systems and technologies that will help make cities more sustainable, resilient, livable, and equitable. Speakers said that as the world population continues to urbanize, the ways in which cities cope with that growth will be among the most critical decisions facing global leaders.

"We are going to be, by and large, an urban species," said Elie Bou-Zeid, a professor of civil and environmental engineering and one of the conference organizers.

Bou-Zeid said that over half the world's population lived in cities by 2005, and that number is projected to grow to 68% by 2050. Over the same time, urban areas are expected to approximately double in size. That poses challenges, but also means that society has a chance to plan and build half of the infrastructure that will support future cities.

"This is a great opportunity," he said. "We really have to try to build these new cities, and retrofit existing ones, better than we have in the past."

Bou-Zeid was followed by keynote speakers Anu Ramaswami, an authority on India and urbanization, and Cameron Carr '03, internet-of-things strategy and sales lead for Microsoft.

Ramaswami, who joined the Princeton faculty on Aug. 1 as inaugural director of the M.S. Chadha Center for Global India, said policies and technologies must take into account the wider regional and global effects of cities.

"Cities have large multiscale impacts outside their boundaries," she said. "It is not about individual widgets and gadgets and gizmos. Those are important, but they sit in this larger frame."

The conference was organized by Princeton's Office of Corporate Engagement and Foundation Relations and The Metropolis Project, with support from Lyft. The participating institutions have since formed a working group to seed further research. **–Amelia Herb and John Sullivan**

CITIES

Urbanization has always been about technology.

Agricultural technology produced the food that made the first cities viable, construction and elevator technologies allowed them to concentrate into small areas while their populations increased, and transportation technology reversed that trend and caused them to sprawl. The big question looking forward is: How will technological breakthroughs — in sensors, models, data analytics, networks, and connected devices — shape the 21st-century metropolis, from the dense urban cores to the distant connected communities and regional Earth systems that are vital for providing the resources cities need?

The associated grand challenge is to guide technological advances on a path that improves urban living. A path that makes future metropolises, as well as smaller agglomerations, more resilient in the face of natural and human-made disasters and shocks, more sustainable in using resources, more socioeconomically equitable, and simply more livable. Given that about 70% of the planet's population will live in urban regions by 2050, and that these built-up agglomerations will be responsible for well over 70% of resource use and anthropogenic emissions, this coming transformation of the city is crucial to the human race's future and its quality of life. It is also why Princeton Engineering has recently launched its Metropolis Project for urban science and engineering.

The Metropolis Project will create a research ecosystem that enables Princeton to play a central role in meeting the urbanization challenge. We will leverage our world-class programs in disciplines necessary to make breakthroughs and shift paradigms about the future of the city: engineering and computer science, natural sciences, architecture, economics, policy, demography, and history, among others. We will also take advantage of our relatively small size, which facilitates and encourages interdisciplinary and fundamental research. Interdisciplinarity has to be at the core of our vision. To have a deep impact, this work requires close interactions between three groups: (i) Developers who advance science and engineer technologies such as algorithms, sensors, structures, models, cyberphysical systems, and many more; (ii) Users who refine and apply innovations to engineer the building blocks and advance the systems of a metropolis (water, communications, government, etc.) — the early adopters of new technologies; (iii) Integrators who examine how the impact of specific technologies, design principles, or engineered systems cascades through the metropolitan system of systems — they design economic, engineering, or policy analyses to achieve practical improvements. Princeton has unique strengths in all these pillars and the vision to see beyond the problems of the few large metropolises of the developed world. We are in a position to lead on the most pressing interdisciplinary inquiries that are required to reimagine the metropolises of the future.

In the following pages, we survey how research of Princeton faculty, students, and postdocs is enabling a better urban future. In the wired city, we consider the important role of new hardware, software, and information networks in collecting and analyzing data and creating knowledge. The sustainable city showcases innovative building blocks of the metropolis such as new materials, structures, and systems. The built city then looks at the larger scale, considering how buildings can be better designed and monitored and evaluating the risks cities incur from natural hazards such as flooding. The livable city surveys sensor technologies and models to monitor and improve urban environmental quality. Finally, the moving city delves into critical and rapid shifts in transportation technology and patterns in the modern metropolis. These are but a few samples of how Princeton researchers work daily to shape a better urban future. **E**

Elie Bou-Zeid is a professor of civil and environmental engineering and the director of the Program in Environmental Engineering and Water Resources.

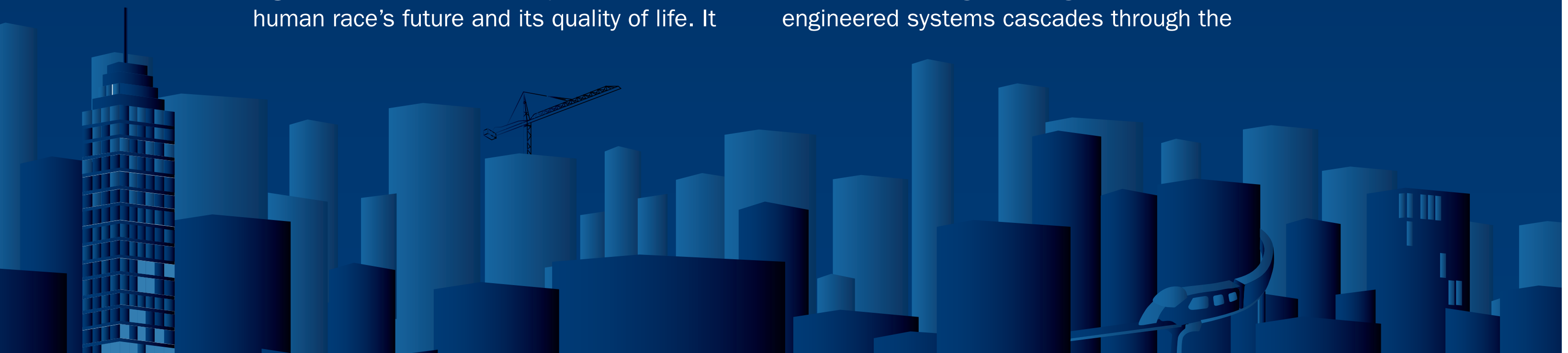


Photo by Sameer A. Khan/Fotobuddy

Elie Bou-Zeid's research uses mobile sensors such as the vehicle-mounted Mobile Urban Sensing Technology (MUST) to gather data about urban environments. The research team included (from left) Hamidreza Omidvar *19, Einara Zahn, Bou-Zeid, and Maider Llaguno.

THE WIRED CITY

In cities of the future, infrastructure will be electronic as well as physical. The sensors and networks that support business, leisure, and everyday life will face much greater demand and scope.

H. Vincent Poor *77
Interim Dean, School of Engineering and Applied Science
Michael Henry Strater University Professor of Electrical Engineering

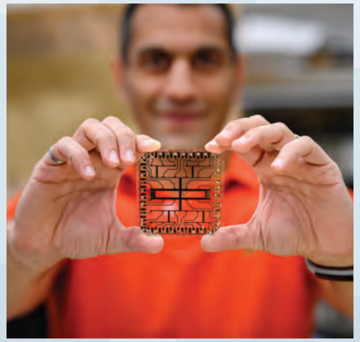
Wireless networks and energy systems
To support the information infrastructure of the future, cities will need wireless systems, including emerging 5G networks that can accommodate traffic from a multitude of smart devices and sensors, and enable the exploding capacity demands of urban communications.

Jennifer Rexford '91
Gordon Y.S. Wu Professor in Engineering

Networks, internet measuring
Rexford is among Princeton researchers who work on measuring and managing information superhighways by giving networks the ability to self-monitor and adapt to traffic in real time.

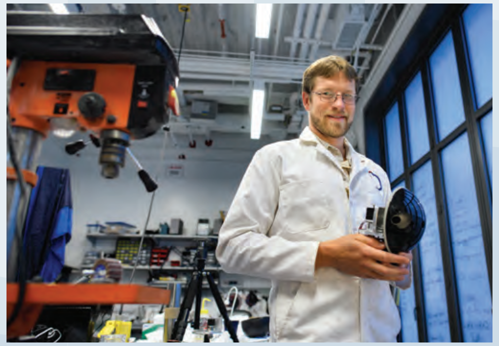
Naveen Verma
Professor of Electrical Engineering

Application-driven circuits
In cities of the future, the most pedestrian elements such as walls, floors, and other surfaces will be self-assessing and self-monitoring. Sensors developed at Princeton Engineering can detect structural damage or chemical changes in the environment, or monitor the activities happening in a space.

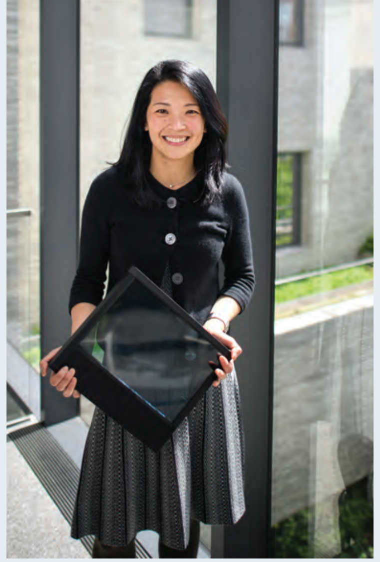


Forrest Meggers
Assistant Professor of Architecture and the Andlinger Center for Energy and the Environment

Building systems design and integration, thermodynamics of the urban environment
Engineering researchers are designing low-energy building systems to harness geothermal power and heat transfer to make buildings more sustainable, comfortable, and efficient.



Text by Amelia Herb, photos by Sameer A. Khan/ Fotobuddy unless otherwise indicated

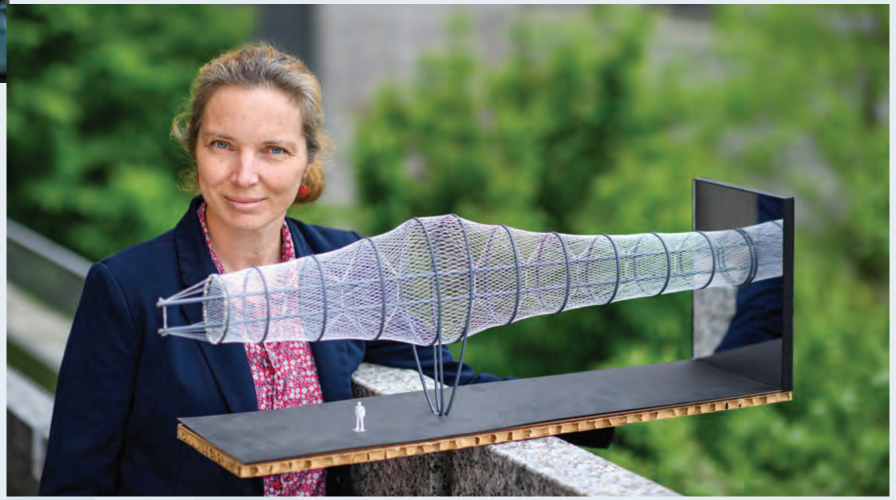


Yueh-Lin (Lynn) Loo *01
Director, Andlinger Center for Energy and the Environment
Theodora D. '78 and William H. Walton III '74 Professor in Engineering

Complex materials and thin-film electronics
Princeton researchers are working to create technology that allows buildings to adapt to their occupants' needs. Devices such as smart windows developed by Loo regulate how much sunlight and solar heat enters the building to improve occupants' comfort and reduce heating, cooling, and lighting needs.

THE SUSTAINABLE CITY

The very structures of cities play an important role in urban environments, from influencing residents' energy needs to affecting local climates and ensuring resilience against natural hazards. Developing new structures and maintaining existing ones are important challenges.



Sigrid Adriaenssens
Associate Professor of Civil and Environmental Engineering

Engineering design framework for the future urban environment
Cities of the future will become increasingly dense, which necessitates highly efficient design. Princeton engineers are rethinking fundamental approaches to structures such as Adriaenssens' ultra-lightweight long-span bridges and buildings, which require a minimum of anchor points.

Claire White
Associate Professor of Civil and Environmental Engineering and the Andlinger Center for Energy and the Environment

Sustainable cement
Expanding cities will mean even greater use of concrete — a major source of greenhouse gas emissions — for buildings, sidewalks, and roads. Researchers at Princeton are working to make concrete more sustainable by replacing conventional cement with lower-energy alternatives including industrial byproducts and processed minerals, together with routes to permanently encapsulate carbon dioxide.

THE BUILT CITY

Structures are cities' building blocks, and as cities grow and change, the role of structures must change as well. In some cases, it means protecting and modifying existing buildings; in others, it means designing new structures to meet emerging needs.

James Smith
William and Edna Macaleer Professor of Engineering and Applied Science

Hydrometeorology, flooding and the hydrologic cycle
Climate change is predicted to worsen flooding that threatens urban systems. Researchers at Princeton use advanced techniques to measure rainfall, gauge atmospheric conditions, and understand the physics of extreme flooding to protect people and cities.

Maria E. Moreyra Garlock
Professor of Civil and Environmental Engineering

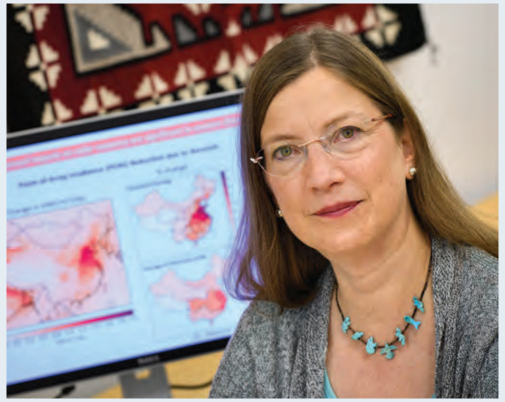
Creative and resilient urban engineering
Future coastlines will become increasingly urbanized, while simultaneously being threatened by rising sea levels and other coastal environmental hazards. Princeton researchers are studying novel building techniques such as elegant thin-shell concrete structures that can withstand these changes.

Branko Glišić
Associate Professor of Civil and Environmental Engineering

Structural health monitoring
New construction techniques are important, but it is estimated that roughly half the buildings that will make up cities in 2050 are already standing today. Princeton researchers are developing techniques to monitor the structural integrity of buildings and infrastructure to signal needed repairs before they become emergencies.

THE LIVABLE CITY

As humanity becomes more urbanized, maintaining health and happiness in crowded environments becomes critical. Clean air, clean water, and efficient transit systems are essential parts of the solution.



Denise Mauzerall
Professor of Civil and Environmental Engineering and Public and International Affairs

Air quality policy
Princeton researchers analyze model results on strategies to reduce air pollution and greenhouse gas emissions around the world. They evaluate the co-benefits of emission reductions for human health, food security, solar electricity generation, and climate change in order to inform productive, far-sighted environmental policies.

Mark Zondlo
Associate Professor of Civil and Environmental Engineering

Atmospheric chemistry and composition
Mobile sensors attached to airplanes or vehicles, combined with sophisticated modeling, allow researchers to identify the emissions of air pollutants and greenhouse gases, thereby helping to improve air quality and the climatic footprints of urban and global environments.

Photo by G. Brad Lewis

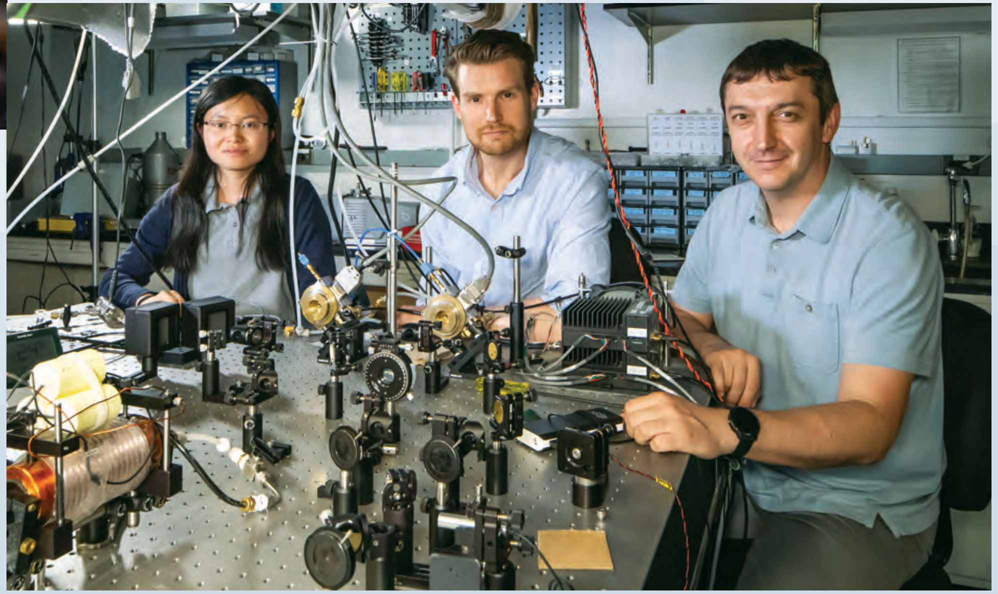


Photo by Frank Wojciechowski

Gerard Wysocki
Associate Professor of Electrical Engineering (Wysocki pictured at right)

Laser-based systems for chemical sensing
Princeton researchers are developing techniques to detect chemical threats to urban environments using sophisticated lasers and sensing systems that offer fast, compact, highly sensitive, and selective detection of airborne molecules.

THE MOVING CITY

Transportation into, out of, and within cities has been one of the key enablers of urban growth. As cities grow larger and more complex, ensuring that people, goods, and information flow smoothly will become all the more important.

Warren Powell ’77
Professor of Operations Research and Financial Engineering

Optimization under uncertainty
Princeton researchers across a range of disciplines work to optimize systems from power grids to transportation networks to ensure that increasingly complex cities will run smoothly despite often-incomplete information.

Photo by David Kelly Crow

Alain Kornhauser *71
Professor of Operations Research and Financial Engineering

Transportation
In future cities, smart-driving, on-demand car fleets have the potential to make transportation safer, more efficient, and more eco-friendly as well as more accessible to older adults and people with disabilities.

Yiguang Ju
Robert Porter Patterson Professor of Mechanical and Aerospace Engineering

Alternative fuels and low-carbon energy conversion
In addition to needing better materials for storing energy in batteries, vehicles of the future will require low-carbon bio-derived liquid fuels that are greener and more efficient alternatives to conventional fossil fuels.

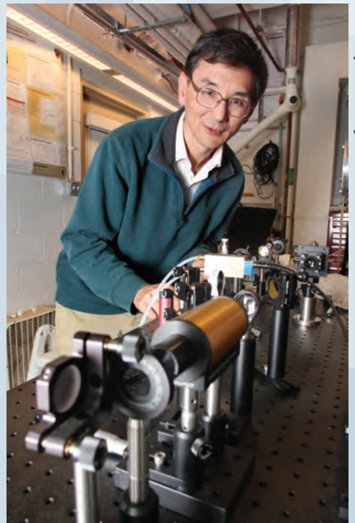
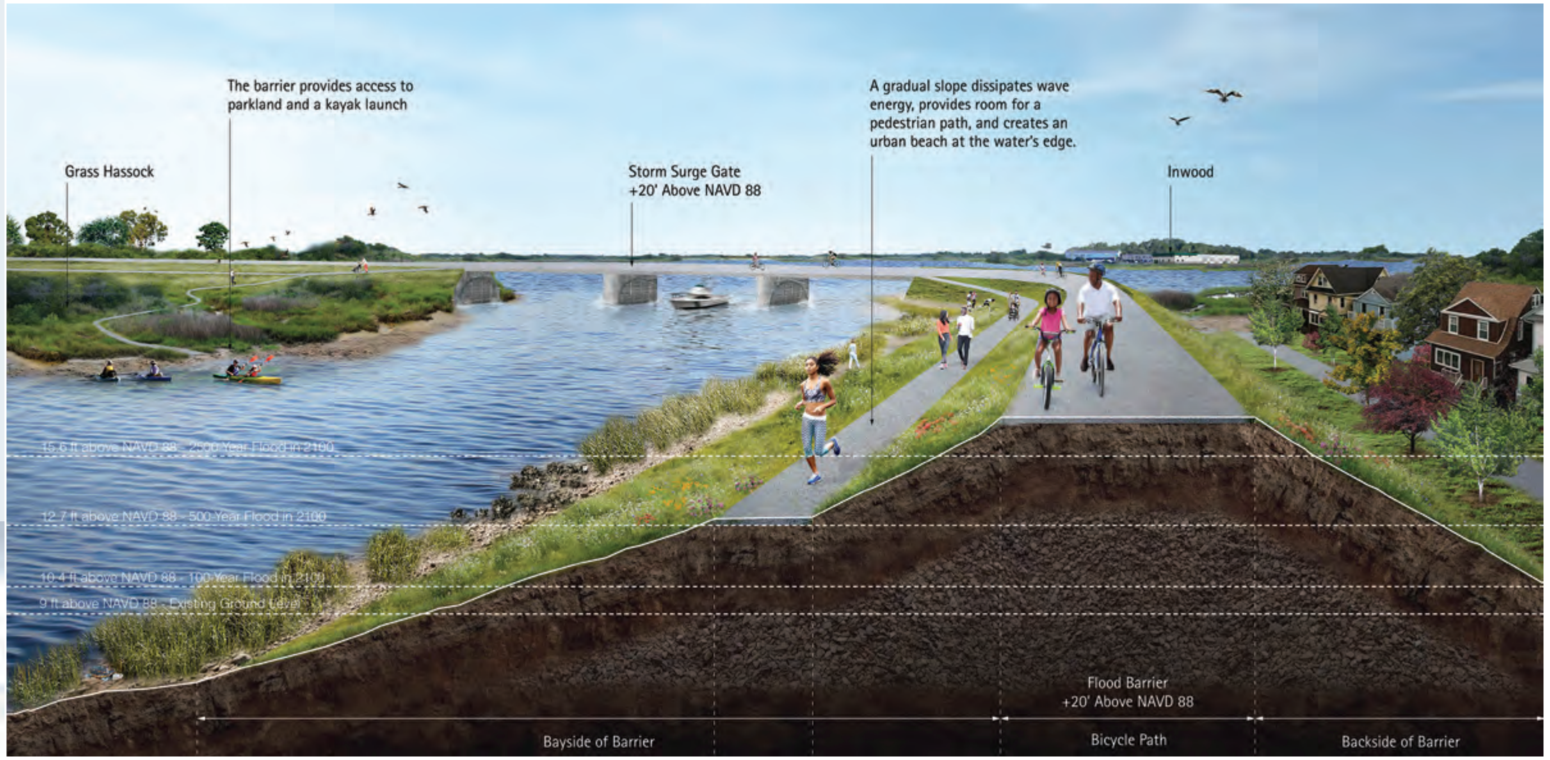


Photo by Frank Wojciechowski

Illustrations courtesy of the researchers



PRINCETON COLLABORATORS BRING LAYERED APPROACH TO RESILIENCY IN NEW YORK CITY

by Steven Schultz

As a microcosm of the challenges facing coastal cities around the world, New York’s Jamaica Bay pretty much has it all.

Home to about 3 million people, one of the world’s busiest airports, and sensitive coastal ecosystems, Jamaica Bay is a lagoon bordered by Brooklyn and Queens at the southwestern edge of Long Island. This region is vulnerable to an evolving set of threats, including sea-level rise, increasingly intense storms, and shifting rainfall patterns.

This complexity makes it a perfect place to apply the cross-disciplinary approach that a team of Princeton University researchers is bringing to improving the resilience of New York and other coastal cities. Culminating years of research funded by the National Science Foundation and supported by the Princeton Environmental Institute, the Princeton team recently published a 170-page report that details existing conditions, analyzes climate and sea-level trends, and proposes solutions to protect Jamaica Bay’s neighborhoods, infrastructure, and ecology.

“We are exploring ways to build resilience that is multilayered and multifaceted," said Guy Nordenson, professor of architecture and affiliated member of the Department of Civil and Environmental Engineering. Along with Nordenson, principal collaborators at Princeton include Ning Lin *10, associate professor of civil and environmental engineering, and Michael Oppenheimer, the Albert G. Milbank Professor of Geosciences and International Affairs and the Princeton Environmental Institute.

In the Jamaica Bay report, the authors propose a two-tiered set of storm barriers: an outer 6.7-mile barrier linking high ground to the north and south of the bay could be closed to protect John F. Kennedy International Airport and other critical areas against extreme events; while a lower, more inland barrier would provide passive protection against tidal flooding as sea levels rise, yet preserve the ecology of the marshes.

The work is part of a larger effort in New York and beyond. Lin, Nordenson, and

Previous page: A team of Princeton architects, engineers, and scientists led an effort to plan solutions that could protect a critical part of New York City from rising seas and intensifying storms. One component is a storm surge barrier that would operate during more intense, less frequent storms.

Oppenheimer are longstanding members of the New York City Panel on Climate Change (NPCC), a group established by the city in 2008 that released its fourth major study in March 2019. By studying and applying solutions in New York, the Princeton team seeks to build a broader methodology for protecting coastal cities.

A key element of the work is combining state-of-the-art climate projections with the particular practical questions that affect cities. Lin said that city officials need details about rainfall, storm surge, sea level, and wind, not just large-scale features such as air and sea temperatures.

"There is a gap between the decision-making and the large-scale climate protections," said Lin. While broad climate projections are critical, she said, regional officials are dealing with more immediate problems. "You are going to make a decision for this building, this dam, this community."

In a talk at an NPCC conference in March, Oppenheimer said the practical work of analyzing hazards and solutions for New York has informed his work as a contributing author to reports for the Intergovernmental Panel on Climate Change, the lead international organization assessing climate change. He cited recent studies, supported by the NPCC, on worst-case scenarios about melting of the Antarctic Ice Sheet and the impact on sea-level rise for cities such as New York. The work is an example of collaborations that "grow from the local to the global, as well as from the global down to the local," he said.

"NPCC provides an example to the rest of the world for how localities can approach the analysis problems characterized by substantial uncertainty, yet deliver science that is ready to be used by policymakers," Oppenheimer said, noting that New York already has made intelligent use of the work.

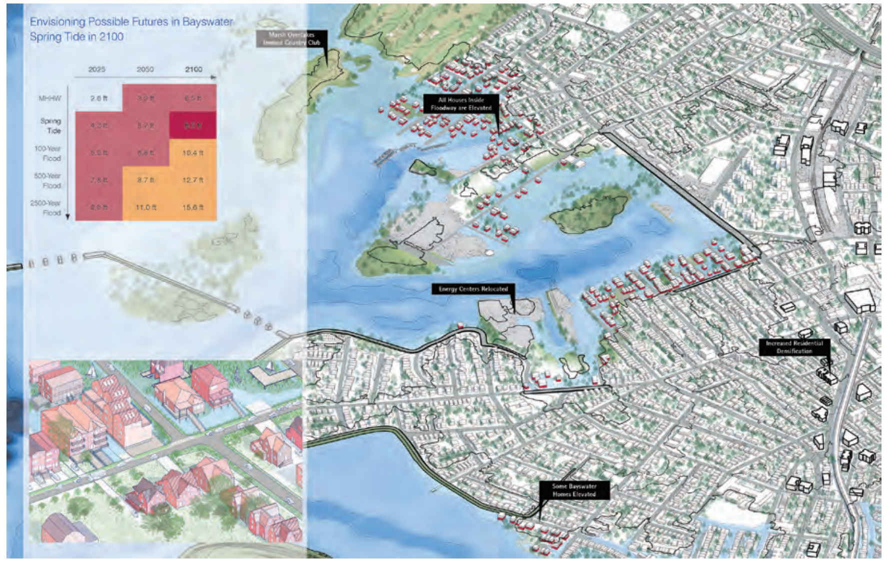
"The NPCC's science, including the Princeton team's integrative work spanning engineering and architecture, has informed everything from our updated building and zoning codes to the design of our large-scale coastal protection projects," said Jainey Bavishi, director of the New York City Mayor's Office of Recovery and Resiliency.

In addition to Nordenson, Lin, and Oppenheimer, the authors of the Jamaica Bay report include Professor of Architecture Paul Lewis *92, graduate alumna Rennie Jones *16, former research scholar Reza Marsooli, and Catherine Seavitt of the City College of New York. Undergraduates Yolanda Jin '20 and Reuben Zeiset '19 also contributed as part of summer internships.

Nordenson said the work includes several broadly useful principles: designing for a range of scenarios, from minor to severe; using world-class science to project how those scenarios are likely to change over decades; integrating multiple layers of solutions, such as a combination of wetlands, barrier islands, seawalls, levies, and dunes; and developing accurate maps of current and future flood risks.

This combined perspective leads to greater creativity and effectiveness, he said. "We can put ideas out there that are bolder than what government folks can put out themselves and that start to pull people in a different direction." E

Below: The planning accounted for a range of storm scenarios and timescales as well as the unique topography, ecosystem, communities, and infrastructure of the region.



FACULTY HONORED FOR DISTINGUISHED TEACHING AND MENTORING

Peter Ramadge, the Gordon Y.S. Wu Professor of Engineering, received the engineering school's 2019 Distinguished Teacher Award. Ramadge's research focuses on machine learning and signal processing. Recently, he has worked with colleagues in neuroscience on analysis of functional Magnetic Resonance Imaging (fMRI). Ramadge also directs Princeton's Center for Statistics and Machine Learning.

Sharad Malik, chair of electrical engineering, said in the award nomination that Ramadge's teaching style "blends a deep commitment to fundamentals with essential real-world examples, providing students with both a firm grounding and a real sense of how to apply their knowledge."

"Peter's teaching is marked by incredible dedication, meticulous attention to detail, and outstanding caring and mentorship for his students," said Malik, the George Van Ness Lothrop Professor in Engineering.

Kenneth Norman, chair of psychology and co-teacher of a course with Ramadge, said in the award nomination that "Peter's approach is to extract the essence of the material and present it with such searing clarity that even students who have seen the material before learn something new."

Emily A. Carter, the Gerhard R. Andlinger Professor in Energy and the Environment, Emeritus, and former dean of engineering, received a Graduate Mentoring Award from the McGraw Center for Teaching and Learning. She was one of four faculty members who received the honor.

Carter was the founding director of the Andlinger Center for Energy and the Environment and served as engineering dean from 2016 until 2019 (see story, page 1). Carter's research combines applied mathematics, quantum mechanics, and physical chemistry to enable the discovery and design of materials for sustainable energy technologies.

Despite substantial administrative duties during her tenure, students described Carter as an attentive and involved mentor. "I always felt that my academic well-being and success remained her priority," said one former advisee.

Matthew Weinberg, assistant professor of computer science, received the annual award for excellence in undergraduate teaching from the Princeton University chapter of the Phi Beta Kappa honor society. He was one of two faculty members who received the award.

Weinberg studies algorithmic mechanism design, algorithmic game theory, and algorithms under uncertainty.

Engineering student organizations have twice honored Weinberg for excellence in teaching for his class on economics and computing.

Students highlighted Weinberg's skill in preparing students for the math and theory requirements in computer science. Citing Weinberg's strength in accommodating the varied experience of students, they noted that his courses "serve as a meaningful stepping stone toward deeper theory for students with more mathematical maturity." And, when students struggle with the material, they are met with Weinberg's "willingness to meet until late hours and for much longer than scheduled in order to get 'un-stuck' on a problem."

Photo by Frank Wojciechowski

Peter Ramadge

Emily Carter, former dean of engineering, shown at the 2019 Class Day, was recognized for her work with graduate students.

Photo by Tori Repp/Fotobuddy

RECENT FACULTY AWARDS, PROMOTIONS, AND HONORS


Photo courtesy of John D. & Catherine T. MacArthur Foundation
Clifford Brangwynne


Photo by David Kelly Crow
Mark Braverman


Photo by David Kelly Crow
Claire White


Photo by David Kelly Crow
Michael Freedman

CHEMICAL AND BIOLOGICAL ENGINEERING

José Avalos
Camille Dreyfus Teacher-Scholar, National Science Foundation (NSF)

Clifford Brangwynne
MacArthur Fellowship, John D. and Catherine T. MacArthur Foundation

Pierre-Thomas Brun
Howard B. Wentz Jr. Junior Faculty Award, School of Engineering and Applied Science (SEAS)

Pablo Debenedetti
Alpha Chi Sigma Award for Chemical Engineering Research, American Institute of Chemical Engineers

Yueh-Lin (Lynn) Loo *01
Defense Science Study Group, 2020-2021

Robert Prud'homme
Edison Patent Award, Research & Development Council of New Jersey

CIVIL AND ENVIRONMENTAL ENGINEERING

Branko Glišić
Fellow, International Society for Structural Health Monitoring of Intelligent Infrastructure

James Smith
Hydrologic Sciences Medal, American Meteorological Society

Claire White
Gustavo Colonnetti Medal, International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM)


Photo by David Kelly Crow
Yueh-Lin (Lynn) Loo *01

COMPUTER SCIENCE

Ibrahim Albluwi
E-Council/GEC Excellence in Teaching Award, SEAS

Mark Braverman
Alan T. Waterman Award, NSF

Bernard Chazelle
Test-of-Time Award, European Symposia on Algorithms

Edward Felten
Distinguished Service Award, Association for Computing Machinery (ACM)
Member, U.S. Privacy and Civil Liberties Oversight Board

Robert Fish
Fellow, Institute of Electrical and Electronics Engineers (IEEE)

Michael Freedman
Grace Murray Hopper Award, ACM

Thomas Funkhouser
Fellow, ACM
Special Interest Group on Computer Graphics and Interactive Techniques (SIGGRAPH) Academy, ACM

Tom Griffiths
Troland Research Award, National Academy of Sciences

Brian Kernighan *69
Member, American Academy of Arts and Sciences (see story, page 3)
E-Council/GEC Excellence in Teaching Award, SEAS

Gillat Kol
E. Lawrence Keyes Jr. / Emerson Electric Company Faculty Advancement Award, SEAS
Sloan Research Fellowship, Alfred P. Sloan Foundation

Wyatt Lloyd *13
Sloan Research Fellowship, Alfred P. Sloan Foundation

Arvind Narayanan
Presidential Early Career Award for Scientists and Engineers, NSF


Photo by Steve Schultz
Arvind Narayanan

Jennifer Rexford '91
Special Interest Group on Data Communications (SIGCOMM) Award for Lifetime Contribution, ACM

Robert Sedgewick
Leroy P. Steele Prize for Mathematical Exposition, American Mathematical Society
Karl V. Karlstrom Outstanding Educator Award, ACM


Photo by David Kelly Crow
Jennifer Rexford '91

Matthew Weinberg
Howard B. Wentz Jr. Junior Faculty Award, SEAS
E-Council/GEC Excellence in Teaching Award, SEAS

ELECTRICAL ENGINEERING

Minjie Chen
Faculty Early Career Development (CAREER) Award, NSF

Yuxin Chen
Young Investigator Research Program Award, U.S. Air Force Office of Scientific Research


Photo by Sameer A. Khan/Fotobuddy
Nathalie de Leon

Nathalie de Leon
E. Lawrence Keyes Jr. / Emerson Electric Company Faculty Advancement Award, SEAS

Jason Fleischer
Defense Science Study Group, 2020-2021

Claire Gmachl
Head of Whitman College

Andrew Houck '00
E-Council/GEC Excellence in Teaching Award, SEAS

Sharad Malik
Intel Outstanding Researcher Award, Intel Corporate Research Council
Distinguished Alumni Award, University of California-Berkeley Department of Electrical Engineering and Computer Sciences

Prateek Mittal
Young Investigator Program Award, U.S. Army Research Office

H. Vincent Poor *77
Benjamin Garver Lamme Award, American Society for Engineering Education
Honorary Doctor of Engineering, University of Waterloo

Peter Ramadge
Distinguished Teacher Award, SEAS

Alejandro Rodriguez
Presidential Early Career Award for Scientists and Engineers, NSF

Jeffrey Thompson
Presidential Early Career Award for Scientists and Engineers, NSF
Sloan Research Fellowship, Alfred P. Sloan Foundation


Photo by Frank Wojciechowski
Jeffrey Thompson

MECHANICAL AND AEROSPACE ENGINEERING

Emily Carter
Distinguished Alumni Award, Caltech

Luc Deike
Faculty Early Career Development (CAREER) Award, NSF

Yiguang Ju
International Prize, Combustion Society of Japan

Andrej Kosmrlj
Alfred Rheinstein Faculty Award, SEAS

Anirudha Majumdar
Amazon Research Award, Amazon.com Inc.
Faculty Research Award, Google AI

Alexander Smits
Fluid Dynamics Prize, American Physical Society

OPERATIONS RESEARCH AND FINANCIAL ENGINEERING

Amir Ali Ahmadi
Presidential Early Career Award for Scientists and Engineers, NSF
Optimization Society Young Researchers Prize, INFORMS (Institute for Operations Research and the Management Sciences)
E-Council/GEC Excellence in Teaching Award, SEAS

Mykhaylo Shkolnikov
E. Lawrence Keyes Jr. / Emerson Electric Company Faculty Advancement Award, SEAS
SIAG/FME Early Career Prize, Society for Industrial and Applied Mathematics
Erlang Prize, INFORMS Optimization Society

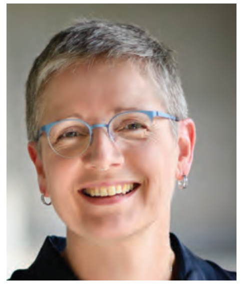


Photo by Sameer A. Khan/Fotobuddy
Claire Gmachl


Photo by Dani Dillena
Amir Ali Ahmadi


Photo by David Kelly Crow
Alejandro Rodriguez

UNDERGRADUATE STUDENT THESES

The thesis experience allows Princeton students to apply the material skills they've learned over four years at the University. With the guidance of faculty advisers, all undergraduates discover new ways to apply their knowledge.

"I am amazed by the resilience and motivation some of them display," said Elad Hazan, a computer science professor. "They truly become researchers." –**Melissa Moss**

Video still by Evelyn Tu

Emily Abdo, *chemical and biological engineering*
Plans after graduation: Working as an engineer for Jacobs Engineering at Johnson Space Center in Houston, Texas
On pushing through: "It's been a challenge, but it also has been a really good lesson in how to start a huge project and take it all the way to completion."

Photo courtesy of Whitney Huang

Whitney Huang, *mechanical and aerospace engineering*
Plans after graduation: Working as an engineer at Zipline International
On theory and application: "Despite my project being on the application side of the research spectrum, having a theoretical basis informing each design decision I made is so important."

Photo courtesy of Maryam Bahrani

Maryam Bahrani, *computer science*
Plans after graduation: Pursuing a Ph.D. in theoretical computer science at MIT
On learning through collaboration: "Collaborating with several people taught me about how my approach to research is sometimes different from others, and how to utilize those differences to produce better work. "

Photo by Kenalpha Kipyegon, Class of 2022

Joyce Kimojino, civil and environmental engineering
Plans after graduation: Working for InterSystems Corporation before attending graduate school
On seeing the bigger picture: "A key takeaway from my thesis research is that there is a big intersectionality between technology and environmental studies, especially in understanding the terrain of energy access in information-starved areas like sub-Saharan Africa."

Video still by Evelyn Tu

Mayee Chen, operations research and financial engineering
Plans after graduation: Starting a Ph.D. in computer science at Stanford University
On new directions in research: "My adviser (Elad Hazan) helped me work through the steps of generalizing my algorithm and pointed out the most interesting directions to take the project. My work with him has shaped my goals of continuing to pursue machine learning research."

Video still by Evelyn Tu

Bhaskar Roberts, electrical engineering
Plans after graduation: Pursuing a Ph.D. in computer science at Princeton
On the intellectual journey: "You learn to push through setbacks even if you're still not getting results after months and months of working on it. Although you never know how far away the next success is, you know that it has to be out there."

CLASS DAY RECOGNIZES CLASS OF 2019 FOR CURIOSITY AND ACHIEVEMENT

The 361 members of the engineering Class of 2019 participated in athletics, dance, musical and theatrical performances, made scientific discoveries and novel technological advances, and served the University and wider community through volunteer work. Graduates went on to pursue graduate and professional degrees; work for employers including Microsoft, Google, and IBM; play professional sports, teach, enter military service, or start new companies. Members of the class have received honors including Fulbright fellowships and National Science Foundation fellowships. At Class Day ceremonies on June 3, the School of Engineering and Applied Science presented the following awards:

Photo by Tori Repp/Fotobuddy

Award winners at the 2019 Class Day

J. Rich Steers Award
Alexander Hsia
Mechanical and Aerospace Engineering
Nyema Wesley
Civil and Environmental Engineering

Jeffrey O. Kephart '80 Prize In Engineering Physics
Ryoto Sekine
Electrical Engineering

Joseph Clifton Elgin Prize
Amber Lin
Civil and Environmental Engineering
Moyinoluwa Opeyemi
Computer Science

George J. Mueller Award
Amanda Brown
Operations Research and Financial Engineering
Maximilian Véronneau
Mechanical and Aerospace Engineering

Calvin Dodd MacCracken Senior Thesis/Project Award
Emily Geyman
Geosciences
Mitchell Hallee
Civil and Environmental Engineering
Gerry Wan
Electrical Engineering

The Tau Beta Pi Prize
Diego Fierros
Mechanical and Aerospace Engineering

The Lore Von Jaskowsky Memorial Prize
Coleman Merchant
Mechanical and Aerospace Engineering
Peter Russell
Electrical Engineering

James Hayes-Edgar Palmer Prize In Engineering
Emily de Jong
Chemical and Biological Engineering
Gavin Zhu
Operations Research and Financial Engineering

Photo by Sameer A. Khan/Fotobuddy

The Graduate School honored seven graduate students with its annual teaching awards in recognition of their outstanding abilities as teachers. Pictured from left to right are Emma Kast, Mattias Fitzpatrick, David Villalobos-Paz, Laura Leal, Dean of the Graduate School Sarah-Jane Leslie, Wasim Shiliwala, Elena Dugan, and George Sorg-Langhans.

GRADUATE STUDENTS HONORED FOR EXCELLENCE IN TEACHING AND SERVICE

Two engineers were among seven graduate students who received the Graduate School's annual teaching awards in April.

Mattias Fitzpatrick graduated in June with a Ph.D. in electrical engineering (applied physics). He served as an assistant in instruction (AI) for "Foundations of Engineering: Electricity and Photonics." He received the electrical engineering department's Richard C. Hough Teaching Award and the Keller Center for Innovation in Engineering Education's Outstanding Teacher Award.

James Sturm '79, the Stephen R. Forrest Professor of Electrical Engineering, said Fitzpatrick developed the entire lab component for the course, which was offered for the first time in spring 2018 to address the preparation of incoming engineering undergraduates. "Due to this new freshman physics/math sequence in the School of Engineering and Applied Science, approximately 20 sophomores are now majoring in engineering who would have otherwise transferred out," Sturm said. "Mattias Fitzpatrick deserves the credit for a large fraction of this result."

Said a student, "It has been very inspiring having a chance to learn from someone so passionate and enthusiastic about their field of study, who also has great skills in simplifying and clarifying the material."

Laura Leal is a Ph.D. student in operations research and financial engineering. She was nominated for her work as a preceptor for "Fundamentals of Statistics."

"Being so close to the students, she understands the difficulties they experience, and being able to channel this information to the instructor of the class is invaluable," said René Carmona, the Paul M. Wythes '55 Professor of Engineering and Finance and professor of operations research and financial engineering. "I have found her insights to be extremely useful when preparing homework problem sets, [and] midterm and final exams, as she knows precisely how the students will fare, and how much further we can push them to achieve their best potential."

Students said Leal was an enthusiastic instructor and dedicated to helping students understand course materials. "What truly sets Laura apart is the care and commitment she shows for each and every one of her students," said one student. "More than any other preceptor I have had, Laura goes out of her way to ensure that her classroom is one in which everyone feels brave enough to try and safe enough to fail." **–Denise Valenti**

GRADUATE STUDENTS BUILD TECHNICAL SOLUTIONS ON STRONG SCIENTIFIC FOUNDATIONS

With a strong basis in fundamental science, Princeton graduate students pursue research that pushes the boundaries of their fields. Some of their innovations involve highly theoretical math, while others emerge from hands-on work in the laboratory or in the field. All use technology to address real-world needs and problems. Projects featured here include computer vision systems, analysis of insect behavior that will inform robotics controls, and techniques to combine historic preservation and environmental sustainability.

JENI SORLI

CHEMICAL AND BIOLOGICAL ENGINEERING

Hometown:
Red Lodge, Montana
B.S.; University of Colorado-Boulder

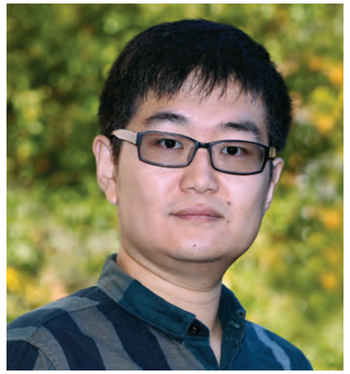
Organic semiconductors enhance technologies including solar cells, lighting, displays, and sensors. They are easier and cleaner to synthesize than traditional materials and can be made into devices that are flexible and relatively inexpensive. Researchers can adjust organic semiconductors' properties by changing their chemical structure. Sorli is developing a deeper understanding of how such changes alter the structures and the optical and electronic properties of organic semiconductors, such as electrical charge transport when the semiconductor is assembled into thin-film structures. Her work highlights the importance of understanding molecular structure and processing conditions to enable future applications of organic materials in electronics.

REBECCA NAPOLITANO

CIVIL AND ENVIRONMENTAL ENGINEERING

Hometown:
Hamden, Connecticut
B.A.; Connecticut College

Historic structures are abundant in cities across the nation, yet millions stand vacant. Napolitano develops tools for documenting, diagnosing, and communicating damage of historic buildings to promote projects such as adaptive reuse and retrofitting. She uses drones and image-based 3D reconstruction work to document structures' conditions, numerical simulations and machine learning techniques to understand how damage could have occurred, and virtual reality to convey this information to a broad audience. This research not only strives to preserve cultural heritage, but also promotes sustainable practices. By recycling buildings, engineers can reduce carbon emissions and material waste in the hopes of creating sustainable cities for the future.



YINDA ZHANG

COMPUTER SCIENCE

Hometown:
Dalian, China
B.E.; Tsinghua University, China
M.E.; National University of Singapore

Zhang, who completed his doctorate in 2018, studied computer vision, allowing artificial intelligence (AI) systems to understand the world through visual inputs, such as in photos or videos. Within this realm, his main research focus was 3D scene understanding, which investigates how to measure the 3D shape and meaning of the surrounding environment. While it is still extremely challenging for computers to fulfill these tasks, Zhang integrated computer vision algorithms with computer graphics and emerging deep-learning techniques to significantly improve their performance. The ultimate goal of his research was to empower the visual perception component of next-generation AI systems with comprehensive and robust scene understanding capability.

KYUNG MIN LEE

ELECTRICAL ENGINEERING

Hometown:
Seoul, South Korea
B.E.; Cooper Union, New York

Organic semiconductors, an alternative to conventional silicon-based electronics, offer exciting opportunities for designing unconventional electronic devices for many uses. Lee's research focuses on building systems with light-emitting organic semiconductors, including flexible displays with high-efficiency and biodegradable electronics. Enabling energy efficiency and biodegradability is an interesting scientific problem, but it also has important practical implications for reducing energy consumption and electronic waste. Lee's most recent endeavor is building light-emitting polymer transistors to drive synthetic chemistry for use in batteries. She hopes to see organic electronics research help solve problems of plastic waste and energy consumption.

RENATO PAGLIARA VÁSQUEZ

MECHANICAL AND AEROSPACE ENGINEERING

Hometown:
Guatemala City, Guatemala
B.S.; Simon Fraser University, Canada

Pagliara Vásquez seeks insights for designing decentralized, robust, high-performance systems that adapt to environmental conditions by studying the collective behaviors of biological systems. He has demonstrated how feedback across different timescales helps regulate ant colonies' foraging, allowing them to thrive in the hot desert region of the southwestern United States. Pagliara Vásquez is also studying the spread of disease to better understand the spread of ideas across networked systems. His work on resilient collective behavior will help illuminate other decentralized biological processes in ecology, medicine, and the environment, and will help create robust and systemic methodologies that enable engineered multi-agent systems to inherit some of the remarkable features of natural systems.

Photos by Frank Wojciechowski

PIERRE YVES GAUDREAU LAMARRE

OPERATIONS RESEARCH AND FINANCIAL ENGINEERING

Hometown:
Denholm, Canada
B.S., M.S.; University of Ottawa, Canada

Gaudreau Lamarre develops mathematical tools using probability to analyze complex physical systems. Often, in a phenomenon called universality, some broad properties of large systems can be observed independent of the system's microscopic details. A problem of great interest to mathematicians and physicists is to understand the mechanisms that cause universality and to build mathematical machinery to study the quantitative features of such systems. Gaudreau Lamarre has helped develop mathematical tools providing a deeper understanding of the universal behavior in some models of interacting particle systems, such as gases of positively charged particles. His goal is to advance this work across multiple types of natural and human-made complex systems.


Frances Arnold

ALUMNI HONORED FOR RESEARCH AND TEACHING

Frances Arnold '79, the Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry, and director of the Donna and Benjamin M. Rosen Bioengineering Center at Caltech, won the 2018 Nobel Prize in Chemistry for pioneering directed evolution of enzymes. Her bioengineering methods for creating new enzymes have benefited industry, medicine, and other fields. Arnold earned her B.S.E. in mechanical and aerospace engineering at Princeton and her Ph.D. in chemistry from the University of California-Berkeley.

Audrey Ellerbee Bowden '01 was named a fellow of the International Society for Optics and Photonics. A professor of biomedical engineering at Vanderbilt University, Bowden graduated with a B.S.E. in electrical engineering from Princeton and a Ph.D. in biomedical engineering from Duke University.

Lance Collins '81, the Joseph Silbert Dean of Engineering at Cornell University, was presented with the Edward Bouchet Legacy Award, which especially recognizes educators and advocates who promote diversity and inclusion. While dean, Collins increased the proportion of underrepresented students significantly, and female enrollment has grown to 50%. Collins has a Ph.D. from the University of Pennsylvania and a B.S.E. in chemical engineering from Princeton, where he serves on the advisory council for the Department of Mechanical and Aerospace Engineering.

J. Alex Halderman '03 *09, a professor of electrical engineering and computer science and director of the Center for Computer Security and Society at the University of Michigan, received an Andrew Carnegie Fellowship. His winning proposal is titled "Strengthening Election Cybersecurity with Evidence-based Elections." Halderman received his A.B. and Ph.D. from Princeton, both in computer science.

Kelvin H. Lee '91 received the 2019 Marvin J. Johnson Award in Microbial and Biochemical Technology from the American Chemical Society's Division of Biochemical Technology. He is the Gore Professor of Chemical and Biomolecular Engineering at the University of Delaware and the director of NIIMBL, the National Institute for Innovation in Manufacturing Biopharmaceuticals.

Lee's B.S.E. in chemical engineering is from Princeton and his Ph.D. in the same subject is from Caltech.


Sindee Simon

Sindee L. Simon *92, the Whitacre Department Chair and Horn Professor of Chemical Engineering at Texas Tech University, was named recipient of the 2019 International Award from the Society of Plastics Engineers. She is the first woman in the society'shistory to receive the award. Simon holds a B.S. from Yale University and a Ph.D. from Princeton, both in chemical engineering.

Avi Wigderson *83, the Herbert H. Maass Professor in the School of Mathematics at the Institute for Advanced Study, was recognized with the Donald E. Knuth Prize for outstanding contributions to the foundations of computer science. His research includes randomized computation, cryptography, and circuit complexity. Wigderson earned his Ph.D. at Princeton in electrical engineering-computer science after receiving his B.A. from the Israel Institute of Technology in 1980.


Avi Wigderson

Photos courtesy of the subjects

ALUMNI TAPPED FOR NATIONAL SERVICE, ADVISORY ROLES

Eric Schmidt '76 joined the National Security Commission on Artificial Intelligence. He heads the group of 15 tech experts who advise the government on national security implications of artificial intelligence and on how to maintain U.S. dominance in the technology market. Schmidt, who has a B.S.E. in electrical engineering from Princeton, is the former executive chairman of Google's parent company, Alphabet Inc.

S. Raja Krishnamoorthi '95 was appointed a member of the House Permanent Select Committee on Intelligence. Krishnamoorthi is a U.S. Representative for Illinois's 8th Congressional District. His J.D. is from Harvard and his B.S.E. in mechanical and aerospace engineering is from Princeton.

Christopher Hart '69 *71, who holds a B.S.E. and M.S.E. in mechanical and aerospace engineering from Princeton, was hired as an independent safety adviser to Pacific Gas and Electric Company to focus on wildfire threats. He also headed delegations examining the Federal Aviation Administration's certification of the Boeing 737 Max airliner. Hart is the former chairman of the National Transportation Safety Board.


S. Raja Krishnamoorthi

ALUMNI NAMED TO LEADERSHIP ROLES IN BUSINESS

Curtis Arledge '87 joined the Mariner Investment Group LLC, an international investment management firm. He serves as chairman and CEO and heads the asset management platform of ORIX USA, a major shareholder. Arledge's undergraduate degree from Princeton is in electrical engineering. He serves on the advisory council of Princeton's Bendheim Center for Finance.


Douglas Boothe

Douglas Boothe '86 was named president and CEO of Akorn Inc., a pharmaceutical company. Previously, he served as president of Impax Laboratories' generic division. Boothe's M.B.A. is from the University of Pennsylvania and his B.S.E. in mechanical and aerospace engineering is from Princeton.

Elizabeth Clymer '03 was appointed CFO of Jobcase, a social media platform where members can manage multiple aspects of their work-lives. She previously spent 10 years as an operating partner at Bain Capital Private Equity. Clymer's B.S.E. in operations research and financial engineering is from Princeton and her M.B.A. is from Harvard.

Thomas Kurian '90, who holds a B.S.E. in electrical engineering from Princeton and an M.B.A. from Stanford, became the head of Google Cloud. He was president of product development at Oracle for over 20 years. Kurian is a member of Princeton's School of Engineering and Applied Science Leadership Council.

Douglas Pagan '93 joined KSQ Therapeutics, a drug discovery company, as CFO. Before this, Pagan was CFO of Paratek Pharmaceuticals, playing a key role transforming Paratek from a development-stage company to a commercial one. His B.S.E. in chemical engineering is from Princeton, and his M.B.A. is from Columbia.


Elizabeth Clymer


Thomas Kurian


Douglas Pagan