Discovery

Research at Princeton 2018-2019

PRINCETON UNIVERSITY

Follow the data

Pablo Debenedetti
Dean for Research
Class of 1950 Professor in Engineering and Applied Science
Professor of Chemical and Biological Engineering

PHOTO BY DAVID KELLY CROW

If there is a theme to this year's *Discovery: Research at Princeton*, it is the ascendancy of data science in aiding our quest for deeper understanding. We now have the computing power and resources to collect, combine and query data in ways not before possible, and this power is growing daily. And with this capability comes the potential to accelerate the pace of discovery and push the limits of knowledge to benefit humanity.

New discoveries also have the potential to contradict what we thought we knew. Research can push us into contentious territory and threaten our deeply held convictions. New ideas should not be rejected just because they challenge existing paradigms. Rather, every new theory, and even many old ones, must be tested against hard facts and data, and through the open exchange of ideas.

When the interpretation of data is influenced by political motives, the results are often detrimental. An example comes from the former Soviet Union, when Stalin endorsed the theories of agronomist and biologist Trofim Lysenko, who rejected Mendelian genetics. Lysenko believed that the right environmental cues by themselves sufficed to train plants to grow at different times of the year, and that such "vernalized" plants would produce offspring that would inherit their growth habits. With Stalin's backing, Lysenko deployed these ideas on a massive scale, setting back Soviet genetics research by decades.

Whatever the controversy of the day, the way forward in science relies on following the evidence, wherever it may lead. Princeton researchers are at the forefront of this path, both through theoretical advances in artificial intelligence and machine learning (page 20), and through innovations in data science that are helping to address societal challenges, such as eviction and its impacts (page 5), energy-efficient transportation (page 7), marine "dead zones" (page 12), attitudes on immigration (page 36), and many more.

The search for understanding is at the heart of University research, whether the quest leads to beautiful theorems, practical inventions or a new interpretation of art (page 26). Princeton is a place where all of these aspects of research coexist, cross-fertilize and intermingle. But why take my word for it? Let the pages of *Discovery* be the data that convince you.

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Discovery
Research at Princeton

2018-2019

Cover: Through advances in artificial intelligence and machine learning, Princeton researchers are building technologies in health care, transportation, energy and many other areas. See our cover story, *From Math to Meaning*, on page 20. Illustration by Daniel Hertzberg.

Research News

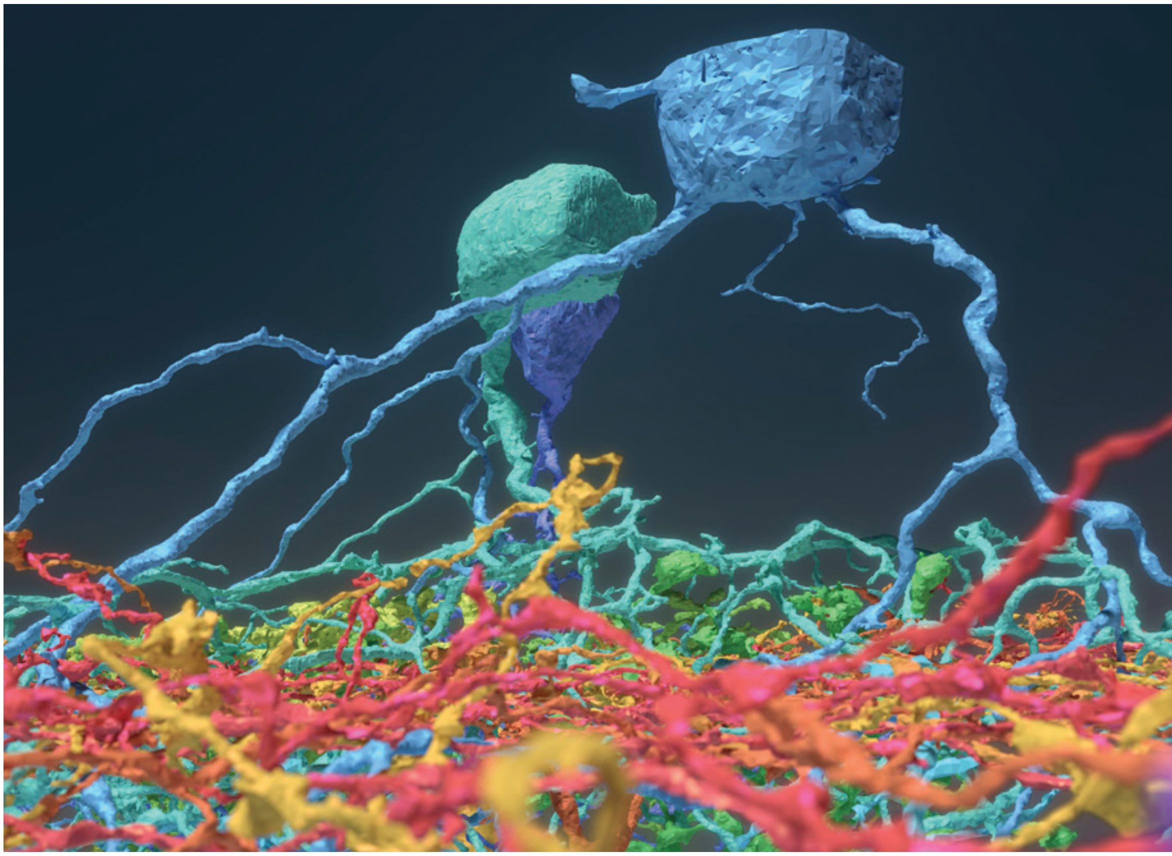


IMAGE BY ALEX NORTON, EYEWIRE

Crowdsourced brain mapping

These neurons, mapped by Eyewire gamers, include ganglion cell types in blue and green and inhibitory neurons in yellow and red.

With the help of a quarter-million video game players, Princeton researchers created and shared detailed maps of more than 1,000 neurons — and they're just getting started.

By playing Eyewire, an online platform that turns a time-intensive research problem into an interactive game, the gamers built an unprecedented data set of neurons. Since Eyewire's launch in 2012, more than 265,000 people have signed onto the game, which asks them to trace the twisting and branching paths of each neuron.

"We've made a digital museum that shows off the intricate beauty of the retina's neural circuits," said H. Sebastian Seung, the Evnin Professor in Neuroscience and a professor of computer science and the Princeton Neuroscience Institute. The research was published in May 2018 in the journal *Cell*.

The new Eyewire Museum is an interactive archive of neurons available to the general public and neuroscientists around the world, including the hundreds of researchers involved with Seung in the federal Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative. Explore the neurons at **museum.eyewire.org**. **–By Liz Fuller-Wright**

Incubator for startups
opens near campus

In May 2018, Princeton officials and local representatives cut the ribbon on the Princeton Innovation Center BioLabs, a 31,000-square-foot co-working lab and office space for high-tech startup companies formed by Princeton faculty, students and alumni as well as members of the wider New Jersey community.

"Increasingly, our students, faculty and researchers seek to make a difference in the world through innovative entrepreneurial ventures that address societal needs," said Princeton President Christopher L. Eisgruber. "Princeton Innovation Center BioLabs is one of several initiatives designed to strengthen the innovation ecosystem in central New Jersey and thereby expand the impact of Princeton's teaching and research." **–By Liz Fuller-Wright**

New supercomputer
bolsters research

Princeton's newest supercomputer, known as TIGER after the University's mascot, began operating this May with nearly six times the computing power of its predecessor.

The TIGER computing cluster, located in Princeton's 47,000-square-foot data center, provides high-performance computing capabilities for research in numerous disciplines.

"A wide range of research crucial to humanity, from investigations of fusion energy to new frontiers in genomics, is now dependent on computers to analyze huge complex data sets and turn predictions into testable hypotheses," said Jeroen Tromp, the Blair Professor of Geology and director of the Princeton Institute for Computational Science and Engineering. **–By Melissa Moss**

PHOTO BY MA. FLOREVEL C. FUSIN-WISCHUSEN

Mental health declining
among disadvantaged adults

American adults of low socioeconomic status report increasing mental distress and worsening well-being, according to a study by Princeton University and Georgetown University.

Between the mid-1990s and early 2010s, mental health declined among disadvantaged Americans ages 24 to 76, according to self-reports. As individuals' socioeconomic status increased, their mental health deterioration lessened or, in some cases, even improved. The findings were highlighted in the *Proceedings of the National Academy of Sciences* in June 2018.

"The findings are consistent with drug overdose death rates and underscore the dire need for improved access to, and affordability of, mental health services for low-income and less-educated American adults of all ages," said Noreen Goldman, the Hughes-Rogers Professor of Demography and Public Affairs at Princeton's Woodrow Wilson School of Public and International Affairs. **–By B. Rose Kelly**

Campus as Lab: Tracking campus ecology

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

As a junior, Artemis Eyster designed and led a class for fellow undergraduates to study the ecology of Princeton's Lake Carnegie through the University's Campus as Lab program.

Artemis Eyster spends more time than most students on the wooded paths near campus where Albert Einstein once cleared his mind.

The Class of 2019 undergraduate, named after the Greek goddess of the wilderness, created a new environmental research course for fellow students in which she and her classmates analyzed the ecology of local areas. They explored areas vulnerable to ecological harm as part of Princeton's Campus as Lab program, which helps faculty and students study real-world environmental issues with the University as a testing ground.

Central New Jersey's mix of small towns, suburbs, farms and nature preserves makes it an ideal place to explore the impact of human activity on the environment.

"If the University wants to make informed decisions based on the natural environment," Eyster said, "it's important that they have a system of monitoring these areas."

Adam Maloof, an associate professor of geosciences, advised the class on an array of sensors and techniques. From aerial photos taken over the past century, the students tracked Princeton's environmental conditions over time. They measured traffic, light pollution, tree counts, plant and animal diversity, and the amount of developed land. They connected those metrics to the health of the University's century-old Lake Carnegie, a popular recreation area.

Eyster's class is one of several projects for the Campus as Lab initiative, which is organized through the Office of Sustainability and supported by the High Meadows Foundation Sustainability Fund.

Eyster ultimately used what she learned to inform her junior-year independent work, and this past summer, she traveled to Panama to study the role of woody vines in forest succession. **–By Kevin McElwee**

PHOTO BY DENISE APPLEWHITE

Eviction Lab
examines the intersection of **poverty and housing**

How many Americans are forced to leave their homes each year?

When Matthew Desmond began investigating evictions in America, it was impossible to answer that question.

"Imagine if we didn't know how many people got cancer every year, or graduated from high school," said Desmond, Princeton's Maurice P. During Professor of Sociology. "This is a major American problem."

His initial deep dive into evictions in Milwaukee led to a 2016 bestseller, the Pulitzer Prize-winning *Evicted*, in which he illustrated the profound connections between landlords, tenants, sheriffs and judges. In the years since, Desmond and the researchers in his Eviction Lab have gathered more than 80 million court records from across the country, painstakingly assembling, cleaning and processing data to create the first-ever national database of eviction records.

They found that about 2.3 million Americans lived in a home that received an eviction judgment in 2016, the most recent year for which they have complete data. And in Virginia that year, one in 10 evictions were for delinquencies less than $340, statistics that Desmond rattled off without notes.

"In 2016 we heard a lot about the opioid crisis, and rightfully so — there were about 65,000 people that overdosed that year," said Desmond, who joined Princeton's faculty in summer 2017. "But that means that for every tragic overdose death, there were 36 people put out on the street. And that's not 'probably' an underestimate, that's absolutely an underestimate, because we still have holes in our data." In April 2018, the team went public with evictionlab.org, where visitors can search for data on almost any city or state, see how their region stacks up against others, look at maps of eviction rates and much more.

"Seeing the map, you are struck by how many families are experiencing housing instability every day, every month, every year," said Lillian Leung, a research specialist with the Eviction Lab. "It's easy to think, 'Oh, this is a problem far away from me,' but the map shows that it's happening everywhere — to people near us. If it's local, it's something you can take action on."

"If you want to take data to your elected officials, our website will automatically create a report on counties you've been evaluating," said James Hendrickson, a senior research specialist. "You can get your county's eviction rate, statistics, demographic characteristics. That's something you can directly take to your city council members, your U.S. representatives, your state senators."

For their "bread-and-butter work," the lab relies on the computers in the Office of Population Research (OPR), and they use the supercomputing clusters at the Princeton Institute for Computational Science and Engineering (PICSciE) for bigger projects, said Hendrickson.

"If it weren't for the computing resources Princeton makes available to us through OPR and PICSciE, this work wouldn't be possible," said Adam Porton, a research specialist. Understanding eviction data is an essential step in figuring out which policies can alleviate poverty in America, said Desmond. "We can't ask those questions if we don't have the data." Learn more at **evictionlab.org.**

–By Liz Fuller-Wright

Matthew Desmond (second from right), author of the Pulitzer Prize-winning 2016 bestseller *Evicted*, and his team created a national database of eviction records, where visitors can see how their region stacks up against others, look at maps of eviction rates, and more.

An overdue spotlight on an avant-garde playwright

PHOTO BY LARRY LEVANTI

Students performed a play inspired by the late María Irene Fornés called *The Book of Miaou-Wow-Wow: Don't Drink Everything Your Mother Pours You*. The cast included Haydon John, Class of 2021 (foreground); and (left to right) E. Harper Nora Jeremijenko-Conley, Class of 2020; Julia Yu, Class of 2019; and Tamia Goodman, Class of 2019.

A symposium and performances held in April 2018 at Princeton focused an overdue spotlight on one of the most influential but perhaps least-known American theater-makers of the 20th century, María Irene Fornés.

Born in Cuba in 1930, Fornés is regarded as a defining force within the off-off-Broadway movement of the 1960s and 1970s. As a playwright, director, designer and teacher, she became a guiding presence for emerging theater artists of the 1980s and 1990s, especially those invested in staging feminist, queer and Latinx aesthetics and experiences.

Associate Professor of Theater Brian Herrera hosted the Latinx Theatre Commons' María Irene Fornés Institute Symposium at Princeton, a national, intergenerational community gathering of more than 100 artists, academics, students and others. The symposium featured performances, conversations and workshops guided by some of Fornés' most eminent former students.

The Program in Theater at the Lewis Center for the Arts also dedicated its main 2017-18 production to Fornés with an evening of two one-act plays: *FNU LNU* by Mac Wellman, a fellow avant-garde playwright, and the world premiere of *The Book of Miaou-Wow-Wow: Don't Drink Everything Your Mother Pours You* by Migdalia Cruz, a student and longtime friend of Fornés. Faculty member Elena Araoz directed both plays, and Cruz's play was commissioned through the Lewis Center's Roger S. Berlind '52 Playwright in Residence program.

Then-seniors Alex Vogelsang and Lydia Watt, Class of 2018, were featured in Fornés' landmark play, *Fefu and Her Friends*, directed by R.N. Sandberg, a lecturer in English, theater and the Lewis Center for the Arts, in the historic Maclean House on the Princeton campus. The students participated as part of their senior theses, which are independent projects required of graduating students.

More than 60 Princeton students were involved in the performance and production of the three plays. The symposium, performances and many other events across the country focused on Fornés in the context of the playwright's decline in recent years due to Alzheimer's disease. At the symposium, participants pledged to preserve and advance the artist's legacy and visibility in the 2019-20 theatrical season and beyond. Fornés passed away on Oct. 30, 2018, with this promise of her work and influence living on through a new generation.**–By Steve Runk**

When driverless ride-hailing services

come to a curb near you

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

Associate research scholar Lina Al-Kanj designs algorithms for optimizing driverless ride-hailing services.

When requesting a ride-hailing service, you may soon notice something missing: the driver. Fleets of autonomous electric vehicles could someday replace human-powered ride-sharing.

Programming obstacles still stand in the way of this happening on a large scale, but associate research scholar Lina Al-Kanj is tackling the unique challenges with Warren Powell, a professor of operations research and financial engineering.

"Driverless cars are becoming a reality, and we already have electric cars on the market," Al-Kanj said. Uber and Google's Waymo each have deals in place for 20,000 or more autonomous cars to hit the roads over the next few years.

Al-Kanj has adapted an algorithm, originally developed by Powell for the trucking industry, to coordinate the actions of thousands of driverless electric cars. One challenge she addressed is the need for autonomous cars to make forward-looking decisions. Currently, ride-hailing apps are nearsighted — they connect the user to the closest car. Al-Kanj's system takes into consideration the charge level of the battery, the length and destination of the trip, when best to recharge the car, and where to position cars to optimize use of the fleet.

Consider a car near Philadelphia with a battery at half charge that gets pinged for a trip to New York City, roughly 100 miles away. Al-Kanj's approach, based on Powell's research on making decisions in the presence of uncertainty, calculates the downstream value of each car based on the projected charge level of the battery after the trip.

Because the vehicles are electric and autonomous, the algorithm must address many other factors that a human driver normally handles: Should the car park and wait for more customers? Should it move to a location with many potential customers? Should it take time to recharge?

These considerations are hard enough to calculate on a case-by-case basis, but when expanded to thousands of cars, the decision-making becomes quite complicated. To handle this complexity, Al-Kanj and Powell developed a framework that scales along with the number of cars in the fleet. Al-Kanj's model allows companies to identify the best locations for recharging facilities, the value of faster charging devices, and the optimal size of batteries for fleet operators.

Al-Kanj hopes that ride-hailing companies will take note of her research, which is funded by the Andlinger Center for Energy and the Environment, so that her logic as well as her strategic simulator can assist fleet operators in real-time dispatch. **–By Kevin McElwee**

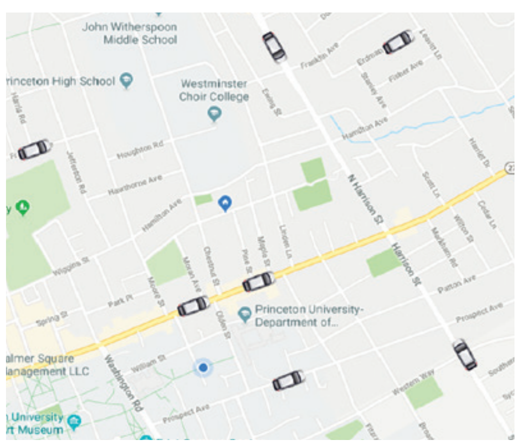


PHOTO BY SAMEER A. KHAN/FOTOBUDDY

Turning up the heat on the search for better plastics

Graduate student Dane Christie is exploring materials that could lead to applications such as self-repairing plastic, high-efficiency solar cells and better batteries.

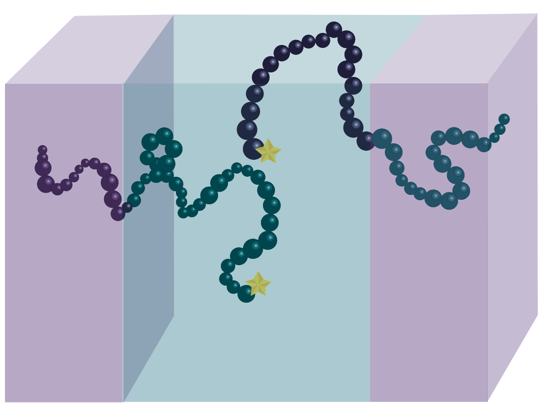
If you have ever poured hot coffee into a cheap plastic cup, you may recall that sinking feeling as the cup seems to wilt. Not quite solid, not quite liquid, the cup totters between two states of matter.

This shift from a hard, glass-like state to a soft and rubbery state is called the glass transition, and understanding it could lead to applications such as self-repairing plastic, high-efficiency solar cells and better batteries.

A research team at Princeton has turned up the heat on the search for a more detailed understanding of plastics by studying the temperature at which materials undergo the glass transition.

The team performed highly precise measurements of the glass transition temperature in plastics known as block copolymers, which are chains of at least two repeating polymer units. What they found could help scientists create new polymers that, like window glass, have an underlying disordered structure that lends strength and durability.

Block copolymers are an active area of research because they can be made to have highly desirable properties, such as healing after mechanical injury and being simultaneously stiff and tough.



Christie attached fluorescent labels to the ends of polymer chains to study the transition from a glass to a liquid state.

"When you think about anything from telescopes probing space to fiber optic cables under the oceans, all of it relies on glass," said Dane Christie, a graduate student in the Department of Chemical and Biological Engineering (CBE) and the first author of a recent paper published in the journal *ACS Central Science*.

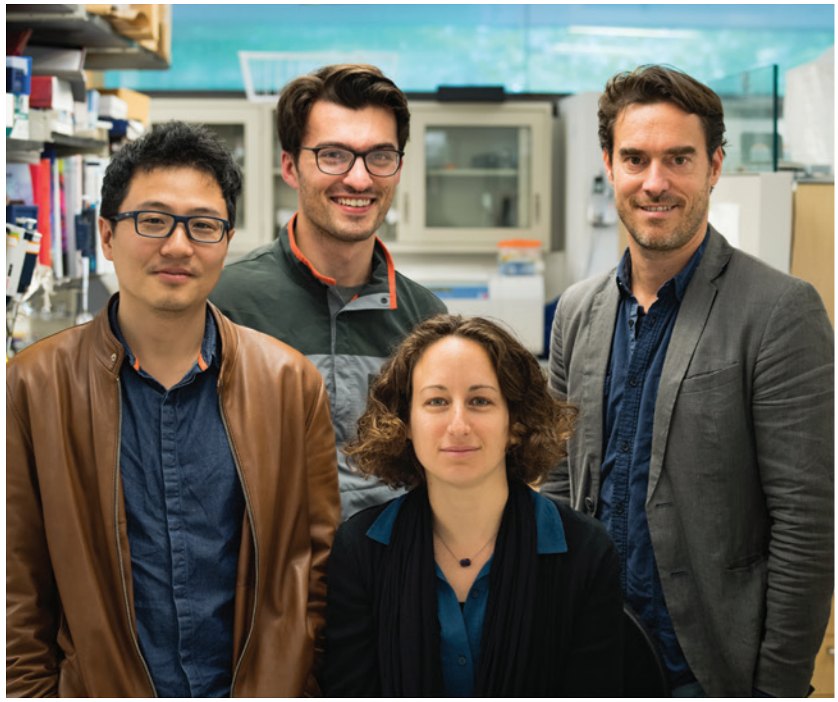
"For most polymers, the glass transition temperature is probably the single most important material parameter," said Richard Register, the Eugene Higgins Professor of Chemical and Biological Engineering, who co-led the study with Rodney Priestley, an associate professor of CBE. "It's what makes a tire rubber rubber and a soda bottle a relatively stiff plastic."

But measuring the exact glass transition temperature of these materials, which self-assemble into shapes that bring various sections of the polymer chains into contact with each other, is not easy. To do so, Christie attached fluorescent labels that allowed him to track the precise movement of the parts of the chain as he raised the temperature. This allowed him to observe how the materials change during the transition from a liquid to a glass state.

The results showed a dramatic and asymmetric change in the intrinsic values of the glass transition temperature within each piece of the chain, especially near the interfaces, facts missed by previous studies.

The study was funded by the U.S. Air Force Office of Scientific Research and the National Science Foundation through the Princeton Center for Complex Materials. **–By Scott Lyon**

PHOTO BY SAMEER A. KHAN/FOTOBUDDY



Thomas Gregor and his team are exploring how pieces of DNA once thought of as junk are involved in the regulation of other genes. From left: Hongtao Chen, Lev Barinov, Michal Levo and Thomas Gregor.

Finding meaning
among the junk

Genes make up only about 10 percent of the human genome. The other 90 percent? Once called "junk DNA," researchers now know that this genetic material contains on-off switches that can activate genes. But how these segments, called enhancers, find and activate a target gene in the crowded environment of a cell's nucleus is not well understood.

Researchers have now filmed the enhancers as they find, connect and activate genes in living cells. The study was published in the journal *Nature Genetics* in July 2018 by an international team led by Thomas Gregor, an associate professor of physics and the Lewis-Sigler Institute for Integrative Genomics.

The malfunction of gene activation causes the development of many diseases, including cancer.

"The key to curing such conditions is our ability to elucidate underlying mechanisms," Gregor said. "The goal is to use these rules to regulate and re-engineer the programs underlying development and disease processes."

Since enhancers are sometimes located far from the gene they regulate, researchers have been puzzled by how the two segments find each other. Previous studies conducted on non-living cells provided only snapshots that omitted important details.

In the new study, researchers used imaging techniques developed at Princeton to track the position of an enhancer and its target gene while simultaneously monitoring the gene's activity in living fly embryos. Hongtao Chen, an associate research scholar and lead author on the study, attached fluorescent tags to the enhancer and its target gene. He also attached a separate fluorescent tagging system to the target gene that lights up when the gene is activated.

Video of the cells let researchers observe how two regions of DNA interact with each other, said Michal Levo, a postdoctoral research fellow. "We can monitor in real time where the enhancer and the gene are physically located and simultaneously measure the gene's activity in an attempt to relate these processes," she said.

The researchers found that physical contact between the enhancer and gene is necessary to activate transcription, the first step in reading the genetic instructions. The enhancers stay connected to the gene the entire time it is active. When the enhancer disconnects, gene activity stops.

Their observations contradict a favored hypothesis known as the "hit-and-run model," which suggested that the enhancer does not need to stay attached to the gene during transcription.

The team discovered that sometimes the enhancer and gene met and connected but gene activation did not occur, a finding they plan to explore further.

The study, which included work by Princeton graduate student Lev Barinov and collaborators at Thomas Jefferson University, was funded by the National Institutes of Health and the National Science Foundation.

–By Kevin McElwee

Bold and cold: A new faculty member and a new microscope explore life's essential molecules

By Kevin McElwee

At the end of a long underground hallway on the edge of campus, a door leads to a brightly lit room. Within looms an imposing 12-foot-tall machine, whose array of wires and tubes can only be seen through a tinted window.

At a table nearby, two researchers prepare the latest sample. They huddle over a bowl from which billows a cool white cloud of liquid nitrogen. The machine behind them is a cryo-electron microscope, one of the world's most sensitive microscopes. It is capable of capturing crisp, three-dimensional images of individual proteins, molecules essential for regulating human health.

Professor Nieng Yan is a leading expert in using cryo-electron microscopy, or cryo-EM, to obtain detailed images of proteins, the building blocks for our muscles, skin, blood, hormones and more.

Last fall Yan returned to Princeton — she'd earned her Ph.D. here in 2004 — as the first Shirley M. Tilghman Professor of Molecular Biology, to lead the University's efforts in cryo-EM — a technology so influential that its development was awarded the 2017 Nobel Prize in Chemistry.

"The future of biology is mapping individual proteins within the cell, or even an entire cell, at atomic scale," Yan said.

Yan was already something of a celebrity before coming to Princeton. While a professor at Tsinghua University, one of China's top research institutions, she garnered more than 450,000 followers on Weibo, a social media platform similar to Twitter. She has published numerous groundbreaking papers on the structures of some of the body's most important proteins, the ones that form channels through the outer membrane of the cell and dictate what comes in and out.

One of these proteins is the sodium channel, a molecule essential to the healthy functioning of the heart and brain. Defective sodium channels are linked to epilepsy, heart arrhythmias, paralysis and chronic pain. In 2017, Yan and her research team published the most detailed picture ever taken of the sodium channel. That image and others like it give biologists a 3-D map through the sodium channel — a guide to help them understand what goes wrong when it fails, and how to design drugs to fix it.

That discovery followed another 2017 publication from Yan's team that illustrated the structure of the vital calcium channel known as Cav1.1. Calcium channels are involved in neurological, cardiovascular and muscular disorders.

The year before, Yan and her team worked out the structure of proteins that control the flux of glucose, the blood sugar that fuels our bodies. Faulty glucose transporters play a role in diabetes. Learning how to shut them off could also be key to starving cancer cells.

At its simplest level, cryo-EM shoots electrons at frozen substances to capture pictures of their atomic structures. As the "cryo" part of the name suggests, each sample needs to be flash-frozen to about minus 180 degrees Celsius to quell its normal movement and harden it against the electron beam.

A sample contains several billion copies of the protein under study, and the device collects thousands of two-dimensional images of each sample. Then a computer identifies each protein, matches like perspectives, and recombines the images together to construct a 3-D volume. By capturing images during different stages of activity, the technique can reveal how the protein functions.

Preparing a sample to go into the cryo-EM takes care, but it is much easier than its main rival technology, X-ray crystallography, which involves laboriously solidifying proteins into crystals. For decades, biologists considered cryo-EM to be crystallography's poor cousin because its images looked more like blobs than like intricately folded chains of atoms. That changed in 2013 with the invention of a new detector technology that yields near-atomic-resolution images.

Paul Shao is Princeton's resident expert in cryo-EM and the specialist responsible for running the machine, a Titan Krios made by Thermo Fisher Scientific. The machine is housed in the Princeton Institute for the Science and Technology of Materials' Imaging and Analysis Center, located in the Andlinger Center for Energy and the Environment.

"High-end instrumentation like this is very sensitive to its environment. Fortunately, one of the most structurally sound places in Princeton just happens to be out that door," said Shao, gesturing past the whirring microscope toward the room's entryway. "It's solid bedrock."

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

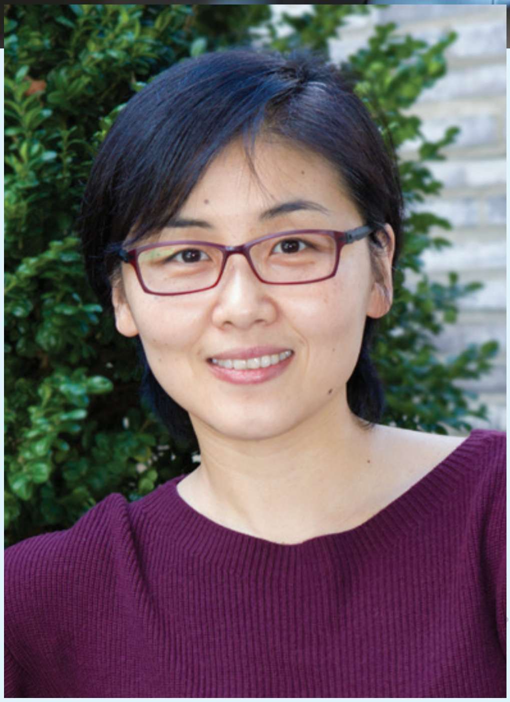


PHOTO BY DENISE APPLEWHITE

Nieng Yan is a global leader in cryo-electron microscopy.

"The future of biology is mapping individual proteins within the cell, or even an entire cell, at atomic scale."

Nieng Yan
Shirley M. Tilghman
Professor of Molecular Biology

Imaging and Analysis Specialist Paul Shao prepares a sample for imaging using cryo-electron microscopy, which Xuelan Wu (center), a graduate student in chemistry, and Nikita Dutta (right), a graduate student in mechanical and aerospace engineering, use for their research.

IMAGE COURTESY OF NASA

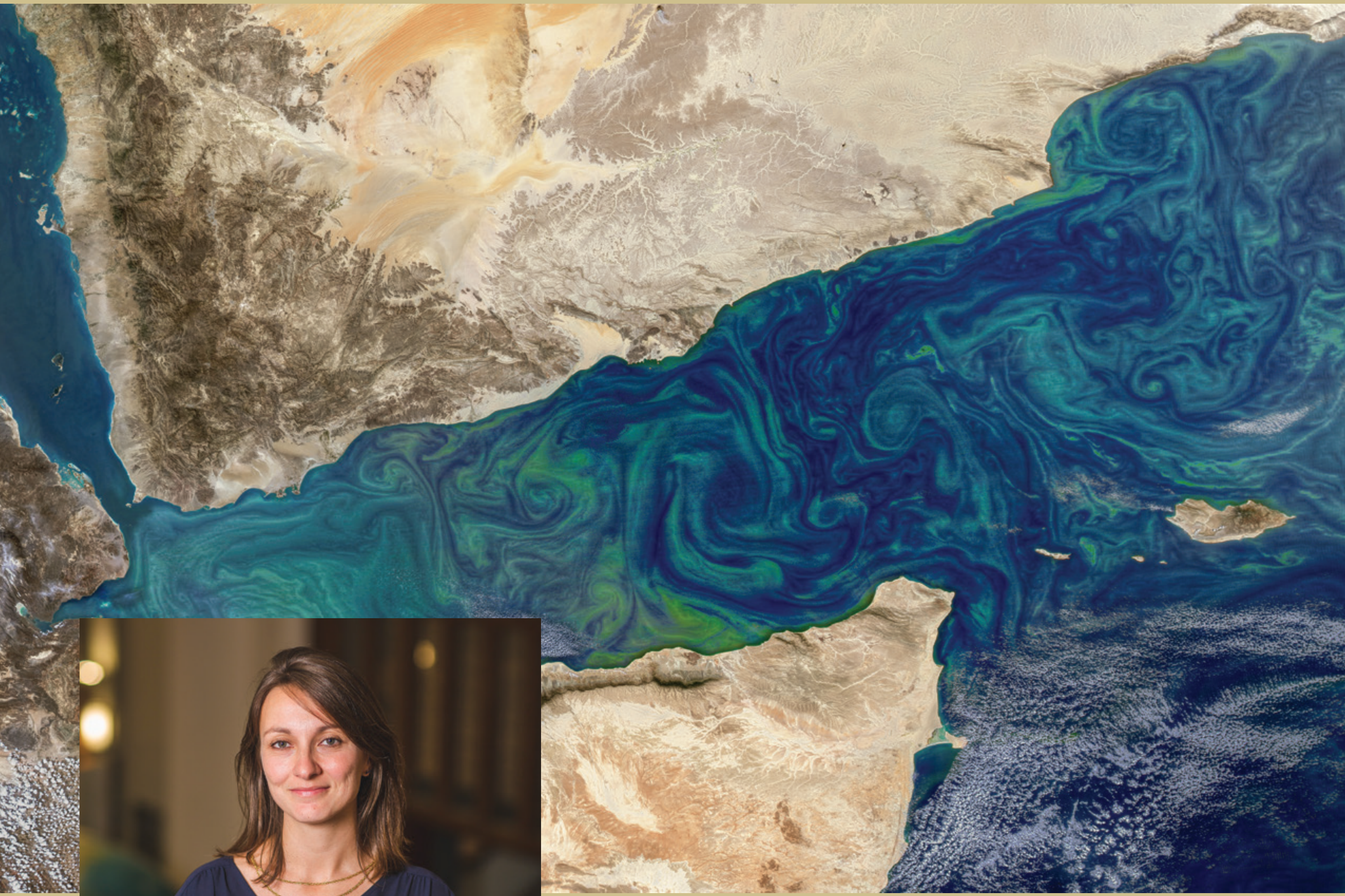


PHOTO BY CHRIS FASCENELLI

Aided by super-computers, Laure Resplandy models how the oceans, atmosphere and climate interact.

"With advanced computing techniques, researchers will soon be able to predict adverse events before they occur, allowing governments to warn communities."

Laure Resplandy
Assistant Professor of Geosciences and the Princeton Environmental Institute

Swirls of algae in the western Indian Ocean's Gulf of Aden indicate the presence of ocean eddies. Laure Resplandy includes eddies in computer models that aim to predict ocean dead zones.

Breathing life into the Indian Ocean
by predicting 'dead zones'

By Kevin McElwee

In 2001, off India's coastal state of Goa, the shrimp catch dropped by 80 percent in just a few years. The die-off was later traced to a dip in the ocean's oxygen level.

"It was a massive event that almost collapsed the fisheries on the western Indian coast," said Laure Resplandy, an assistant professor of geosciences and the Princeton Environmental Institute, who studies how our oceans, atmosphere and climate interact. "One of the Indian fishing industry's biggest sources of income is the export of shrimp to the United States."

Resplandy believes that researchers, aided by advanced computing techniques, will soon be able to predict events such as these before they occur, allowing governments to warn communities or to prevent such occurrences altogether. She and her collaborators, including scientists at the Geophysical Fluid Dynamics Laboratory (GFDL), a division of the U.S. National Oceanic and Atmospheric Administration located about 3 miles from Princeton's campus, are developing computer models aimed at making this goal a reality.

Tropical regions in the Indian Ocean are predisposed to low oxygen levels because exchanges with the atmosphere are limited and the water is warm. In higher latitudes, rough seas can take in and dissolve more oxygen from the atmosphere, and colder oceans can contain more oxygen.

"If you leave your Coke in the sun, it'll lose most of its fizz fast," Resplandy explained. "Warmer liquids hold less gas than colder ones."

Although low-oxygen regions occur naturally, human activity is the likely culprit when oxygen levels plummet so far that ocean life starts to die. In many coastal areas, agricultural fertilizers spur the growth of algae, which in turn become food for microbes that consume the oxygen, creating massive "dead zones" devoid of aquatic life. Because India's agriculture is growing along with its booming population, the Indian Ocean is particularly susceptible.

To learn more about how and when these coastal dead zones can arise, Resplandy and her colleagues developed models with hundreds of factors, including algal production of oxygen, the mixing of fresh and salt water, and the ocean eddies that promote algae growth and oxygen exchanges between surface and deeper waters. She also includes variables controlling the monsoon, the massive system that dictates almost all weather patterns in South Asia.

Her models don't have enough computing power to track every single wave and eddy in the ocean, but with informed estimations, she can create a model that approximates what to expect. She and her collaborators run these models on supercomputers in Princeton's TIGER research computing cluster and at Oak Ridge National Laboratory. They then compare their models' predictions to the measurements of oxygen levels, water temperatures and algae growth collected over the past century. If a model draws an accurate picture for recent events, its predictions for the future are more trustworthy.

John Dunne is a research oceanographer at GFDL who collaborates with Resplandy. He heads GFDL's Biogeochemistry, Ecosystems, and Climate Group and has over 20 years of experience in collecting field observations, analyzing data and performing modeling.

Dunne was impressed with Resplandy's breadth of research. "She now has many examples of research in which she has become engaged and advanced the understanding of the topic," he said. "She's a person that Princeton is lucky to have in their arsenal of scientific innovators."

Resplandy was drawn to the Indian Ocean when writing her doctoral dissertation while at the Laboratoire d'Océanographie et du Climat in France, where she developed a model for addressing similar biogeochemical questions that is still used by the Indian government.

More recently, her models offered oceanographers a detailed picture of how oceans and rivers carry the Earth's carbon and impact the storage of carbon on land, research that was published in June 2018 in *Nature Geoscience*. She has also received funding from NASA to collaborate with colleagues at the Jet Propulsion Laboratory and the Scripps Institution of Oceanography on a study of carbon fluxes during El Niño events.

Resplandy hopes that her new project on oxygen levels in the Indian Ocean, which is funded through the Princeton Environmental Institute's Grand Challenges program, can also aid Indian officials. She doesn't see herself as a policy advocate, but she expects her models to lead to preventative measures, such as safeguards to reduce fertilizer runoff.

She recognizes the magnitude of the questions she is trying to answer. "It's challenging," she said. "I'd do something else if it weren't."

Treasure in ancient trash

By Kevin McElwee

Thomas Conlan fiddled with a strange, brownish-black rock on his desk. For centuries, people had considered the piece of rubble worthless, but it is priceless to Conlan's research.

The lumpy rock is a sample of slag, the material left over after heating ore to extract valuable metals. With researchers from art, engineering and materials science, Conlan is exploring whether these discarded scraps can fill gaps in early Japanese history.

Conlan, a professor of East Asian studies and history, hopes to use the mining waste to learn about the political and cultural climate of Japan in the eighth to 18th century CE, a period for which written records are sparse.

Much of Conlan's slag comes from the smelting of copper, a metal that played an important role in historical trade, monuments and coinage. "We know there was an incredibly vibrant process of metallurgy in the past," Conlan said. "They were mining tons of this stuff, but there's nothing really written about it."

Some products of these early copper mines can still be seen today. The world's largest bronze Buddha, located in Nara, Japan, dates from 745. Its construction required nearly 490 tons of copper from a nearby mine, as described in documents from that period. But from the 10th to the 16th century, very few records discuss mining, leading researchers to wonder whether metallurgy declined or was simply not documented.

This lack of textual records can sometimes skew historians' perspectives, Conlan said. "Historians have overestimated the importance of rice and agriculture," he said. "And they have underestimated the importance of mining and trade."

Conlan hopes to correct this imbalance by probing the microscopic structure of slag. He obtained 30 or so samples, dating from 700 to 1700, from colleagues in Japan. Using state-of-the-art methods with support from the David A. Gardiner '69 Magic Project fund for innovation in the humanities, his team wants to learn the techniques of medieval metallurgists, including what additives were mixed in the metals, what temperatures were used and how the materials were refined.

Conlan's collaborators on the project are Howard Stone, the Donald R. Dixon '69 and Elizabeth W. Dixon Professor of Mechanical and Aerospace Engineering; Nan Yao, a senior research scholar with the Princeton Institute for the Science and Technology of Materials (PRISM) and director of the Imaging and Analysis Center; and Rachel Selinsky, an associate research scholar in mechanical and aerospace engineering. Conlan was also advised by Craig Arnold, a professor of mechanical and aerospace engineering and the director of PRISM, and Bruce Koel, a professor of chemical and biological engineering.

At a recent meeting to discuss the project, the researchers huddled around a desk in Conlan's book-lined office, far from the sterile labs and whirring machines in the imaging center.

Material scientists have analyzed slag in the past, but the researchers think this is the first time that slag has been used to investigate a region's history.

"There's a kind of detective problem here," Stone said.

"It's like trying to figure out a puzzle without having all the pieces," Nan said.

"It's like figuring out what a forest looked like from 30 leaves," Conlan said.

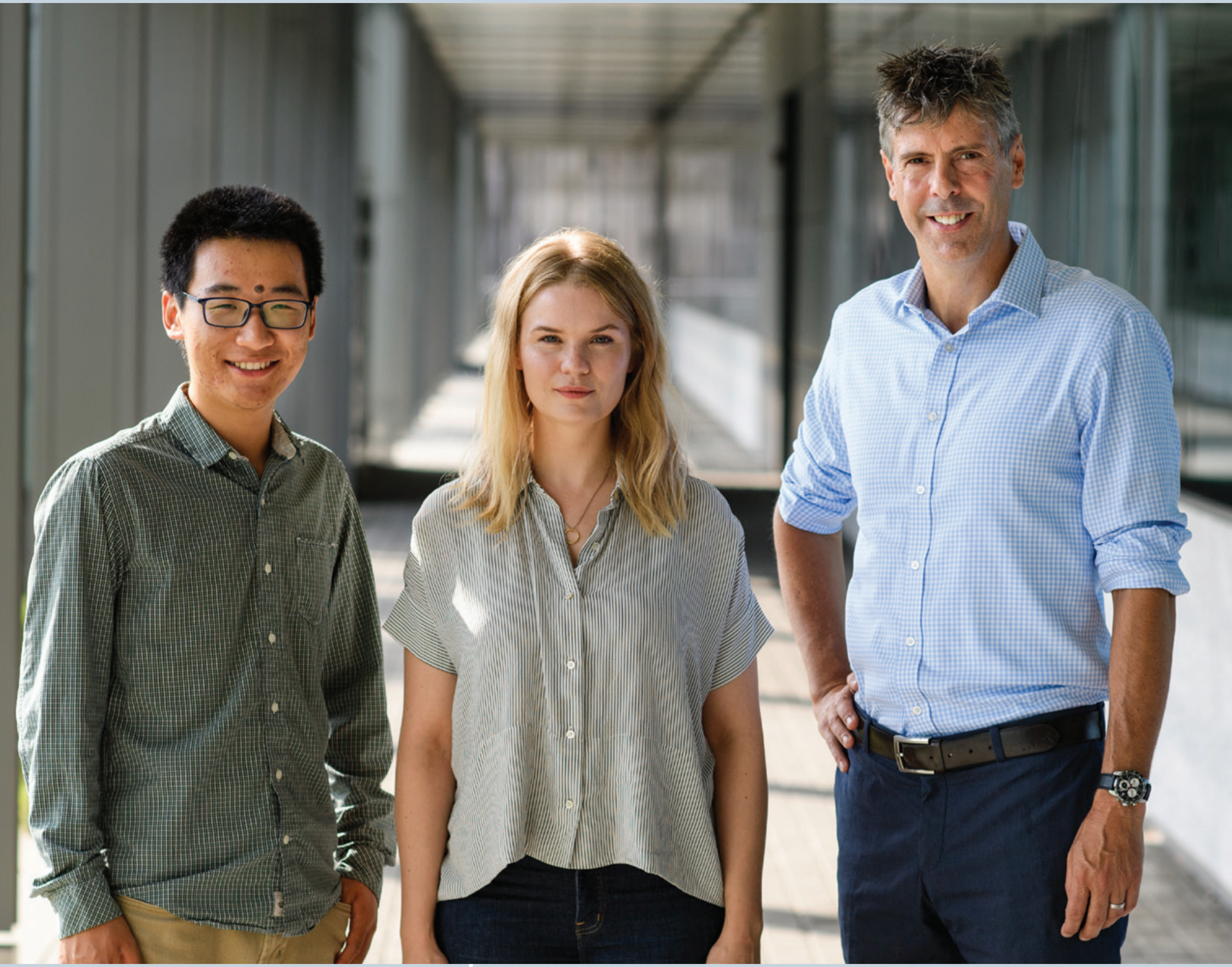
Selinksy is in charge of conducting the experiments, which include identifying a sample's constituent elements by shooting X-rays at it and measuring what is emitted in response. So far, the data suggest that Japanese metallurgists did not add any ingredients, such as calcium, to improve the extraction of copper.

The team has now turned their attention to the slag's crystallographic composition, using different tools to see if the material's history is locked in its structure.

If their work does identify improvements in metallurgy through time, the research could fundamentally change the way historians not only look at early Japan, but how they view the historical role of copper worldwide. Many early economies depended on copper production, and these techniques may well shine light on other ancient civilizations that left few written records.

Researchers are using modern materials analyses to learn about medieval metallurgical practices, depicted here in the book *Kodō zuroku* by the Sumitomo Family. The book dates to 1795 and describes how to extract copper from ore.

PHOTO BY SAMEER A. KHAN/FOTOBUDDY



Are the quantum laws of nature the secret to plants' efficiency at harnessing energy from sunlight? A team led by Gregory Scholes (right), plans to find out. The team includes graduate student Ben Xinzi Zhang (left) and postdoctoral research associate Kyra Schwarz.

"There's an ongoing quest to find new, compelling examples of the use of quantum mechanics in biology."

Gregory Scholes
William S. Tod Professor of Chemistry

Going quantum
to unlock plants' secrets

By Kevin McElwee

When it comes to green living, nobody does it better than plants. When plants convert light into fuel through photosynthesis, not a single particle of light is wasted. If we could unlock plants' secrets, we might be able to perfect the design of light harvesting in solar cells.

Gregory Scholes, Princeton's William S. Tod Professor of Chemistry, suspects that the key to plants' efficiency stems from their ability to harness quantum physics, the unintuitive behaviors of very small particles. In 2010, he led a team that demonstrated quantum effects in marine algae.

But the finding was not without controversy. Quantum behaviors usually reveal themselves at extremely low temperatures isolated from real-world disturbances, raising questions as to whether these quantum states can survive the warm and wet conditions of life.

So Scholes and his team decided to probe quantum behavior in one of the simplest known chemical reactions, the transfer of a hydrogen atom from one part of a molecule to another. If their experiments work out, the researchers could rewrite our understanding of how chemical reactions occur.

At the heart of quantum theory is the idea that matter can behave both like particles and like waves. If we fire particles at a barrier containing two slits, classical physics predicts that the particles will land in two piles, one behind either slit. In contrast, quantum mechanics predicts that each particle will act like spread-out waves and pass through both slits (see figure), where the intensity at any point can either add together or cancel itself out.

This quantum nature of matter, known as a superposition, has been predicted and observed since the 1920s, and has helped us comprehend the microscopic world. However, these quantum ideas have not yet shaped the understanding of chemical reactions.

"That's the big question we're trying to answer," Scholes said. "Can we harness quantum mechanics to work for us in chemistry?"

The researchers addressed the question by studying what happens when light hits a molecule that can undergo two separate hydrogen transfer reactions, one on the left and one on the right side of the molecule. If classical rules prevail, then each reaction will proceed one step at a time. If quantum rules are involved, both the left and the right reaction will occur in a quantum superposition.

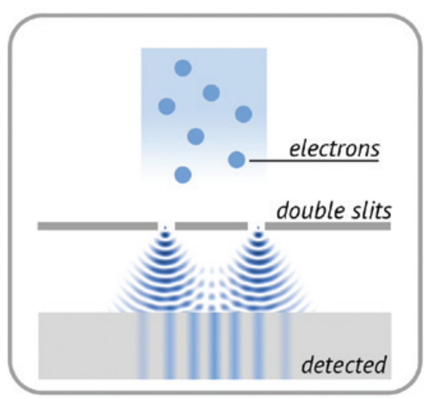
To find out if this is happening, Scholes' team set up an experiment to take snapshots of molecules during the reaction. With funding from the W.M. Keck Foundation, the researchers bombard the molecules with pulses of laser light, which place the normally chaotic molecules into the same quantum rhythm. "We use light to synchronize molecules so that they all dance to the same beat," said graduate student Ben Xinzi Zhang.

Next, to see if the molecules are indeed in a superposition, researchers use a second laser pulse. It monitors the state of the molecule using rapid bursts that light up the positions of the atoms like a strobe light illuminating a dancer.

The researchers then look for patterns from reaction pathways that add and cancel, just like in the double-slit experiment. "The signatures will tell us how these two sides are interacting," said Kyra Schwarz, a postdoctoral research associate on the team.

The results of the experiment are not yet in, but if quantum superposition plays a role in a reaction as ubiquitous as the transfer of hydrogen, it could underlie many processes in nature. The result could also reshape how chemical reactions are conceptualized and understood across disciplines, making it possible to leverage quantum properties to control and create new reactions.

Scholes will also lead a new Energy Frontier Research Center, announced in July 2018 and funded by the U.S. Department of Energy, to study how light harvesting and solar photochemistry can make new molecules and fuels. The center includes faculty members at Princeton as well as national laboratories and leading universities.



Quantum mechanics predicts that each particle will act like spread-out waves and pass through both slits.

Engine of cosmic evolution

Eve Ostriker looks under the hood

By Catherine Zandonella

Outside Eve Ostriker's office door stretches the universe, dotted with orange galaxies against the black backdrop of space.

The mural lines the hallway in Princeton's astrophysical sciences building, where it inspires Ostriker to explore what lies beyond our own galaxy, the Milky Way. How did those far-flung galaxies grow and evolve?

"It is the story of 'How did we get here?' but it is not just us, it is all of the galaxies," Ostriker said. "I'm motivated by wanting to understand how the universe works. And the fact that we now have the tools to do this just makes it all the more exciting."

The tools she uses are powerful supercomputers and algorithms capable of simulating the birth, life, death and reincarnation of stars in their galactic homes. Ostriker, a professor of astrophysical sciences, and her collaborators and students build computer models using fundamental physical laws — ones that govern gravity, fluid dynamics and electromagnetic radiation — to follow the evolution of conditions found in deep space.

Interstellar ecosystem

Beyond the edges of our solar system lies the interstellar medium, the space between stars. This is the "engine of cosmic evolution," Ostriker said, where gases — mostly hydrogen and some helium — coalesce to form new stars, which grow, burn brighter and eventually die.

Fueling this engine are massive stars — those 10 times the mass of our sun. They pour out particles of ultraviolet light that ionize the gas around them and keep even distant parts of galaxies warm. When they die, these stars explode as supernovae that rapidly expel gas into the interstellar medium.

"Without massive stars to return energy to the system and keep the interstellar medium warm and stirred up, everything would be kind of dead," Ostriker said.

A big puzzle is what causes the torrent of gas flowing out of galaxies, particularly at early stages of cosmic evolution. Telescope observations show outpourings of gas called galactic winds. Ostriker and her team are modeling how supernovae can spur formation of these winds, as well as galactic fountains of gas in the Milky Way.

Modeling the various parts of the picture — star formation, galactic winds and the rest of the interstellar ecosystem — requires bringing together a number of astrophysical concepts. The timescales over which things happen can be very long — billions of years — or very short, on the order of days.

After identifying the crucial physical details, researchers create a computer model in which a galactic region is divided into a grid consisting of hundreds of millions of cells. If the models, as they run forward in time, give results that look similar to actual astronomical observations, then the researchers are on the right track.

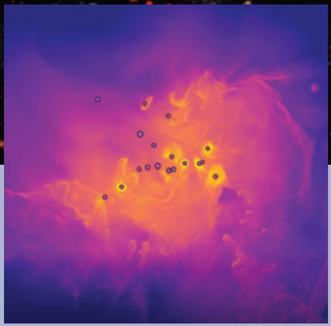
Bubbles and clouds

One area Ostriker explored with her team was the formation of superbubbles, giant fronts of hot gas that billow out from a cluster of supernova explosions. The spreading bubble drives heat and turbulent gas out into the interstellar medium, fueling the cosmic engine. The project included work by then-undergraduate Roberta Raileanu of the Class of 2016 and Chang-Goo Kim, an associate research scholar jointly appointed at Princeton and the Simons Foundation's Flatiron Institute.

More recently, Ostriker and her colleagues turned their focus toward interstellar clouds. Jeong-Gyu Kim, a Lyman Spitzer, Jr. postdoctoral fellow at Princeton, developed a way to track how light moves through, and ultimately disperses, the clouds of gas surrounding nascent star clusters. Alwin Mao, a graduate student, explores how dust and gases collapse to form stars. Munan Gong, who earned her Ph.D. at Princeton in 2017, studies molecules and dust in the clouds.

The research team uses computing resources through the Princeton Institute for Computational Science and Engineering and its TIGER and Perseus research computing clusters, as well as supercomputers administered through NASA. "It is fantastic that the University offers high-performance computing resources," Ostriker said. "It means that a student working on a new project can do cutting-edge research right away."

PHOTO BY SAMEER A. KHAN/FOTOBUDDY



J.-G. KIM, W.-T. KIM, AND E.C. OSTRIKER 2018, *THE ASTROPHYSICAL JOURNAL*

Interstellar clouds form star clusters that ionize and disperse gas.

"It is the story of 'How did we get here?' but it is not just us, it is all of the galaxies."

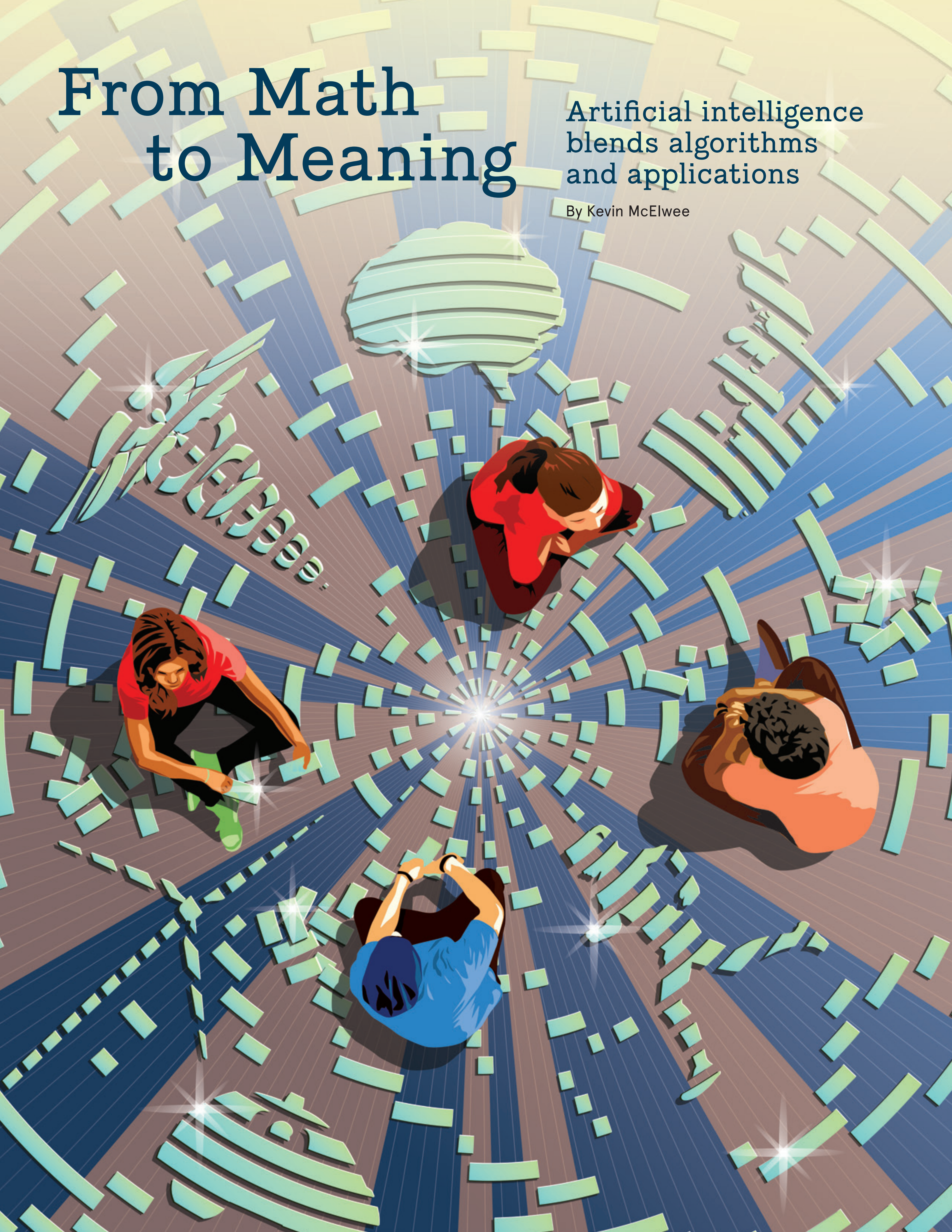
Eve Ostriker
Professor of
Astrophysical Sciences

Astrophysicist Eve Ostriker investigates the evolution of stars and galaxies.

From Math to Meaning

Artificial intelligence blends algorithms and applications

By Kevin McElwee



Artificial intelligence is already a part of everyday life. It helps us answer questions like "Is this email spam?" It identifies friends in online photographs, selects news stories based on our politics and helps us deposit checks via our phones — if all somewhat imperfectly.

But these applications are just the beginning. Through advances in computer science, researchers are creating new capabilities that have the potential to improve our lives in ways we have yet to imagine. Princeton researchers are at the forefront of this research, from the theoretical underpinnings to the new apps and devices to the ethical considerations.

Attempts at building intelligent systems are as old as computers themselves. Early efforts often involved directly programming rules of behavior into a system. For example, researchers might input the laws of motion to control a robotic arm. But the resulting behaviors usually fell short.

With artificial intelligence, computers learn from experience. Through "machine learning," a subfield of artificial intelligence, computers are programmed to make choices, learn from the outcomes, and adjust to feedback from the environment.

Machine learning is transforming scholarship across campus, said Jennifer Rexford, Princeton's Gordon Y.S. Wu Professor in Engineering and chair of the computer science department.

"Princeton has a very long tradition of strong work in computer science and mathematics, and we have many departments that are just top notch, combined with an emphasis on serving humanity," Rexford said. "You just don't get that everywhere."

Positive outcomes

One societal challenge that artificially intelligent machines are addressing is how to make better health care decisions. Barbara Engelhardt, an associate professor of computer science, is creating algorithms to help doctors adopt practices most likely to have positive patient outcomes.

For example, when should a patient be weaned from a ventilator? Used by one in three patients in intensive care units, a ventilator is a life-saving device, but is invasive, costly and can spread infection. Doctors often wait longer than necessary to remove a patient from a ventilator, because if they are wrong, they could complicate the patient's health further.

In partnership with researchers at the University of Pennsylvania's hospital system, Engelhardt and her team aim to move patient care away from a one-size-fits-all approach to one that is tailored to individual patients. Their algorithm considers many patient factors and then calculates when and how to remove the patient from the ventilator. It makes numerous decisions, including how much sedative to give prior to the procedure and how to test whether the patient can breathe unassisted.

Machine learning could also help in situations where high-quality human healthcare is not immediately available, such as with patients in palliative care, who could be monitored around the clock as if by a specialist.

Reinforcement learning

Engelhardt uses a machine-learning approach called reinforcement learning, a departure from the older but still widely used practice of "supervised learning," where programmers provide computers with training sets of data and ask the machines to generalize to new situations. For example, to teach a computer to identify dogs in photos, programmers provide tens of thousands of images, from which the computer develops its own rules to figure out whether new photos contain a dog.

Reinforcement learning, by contrast, is more like the trial-and-error learning that young children use. A toddler who tries to pet the family cat and receives a sharp swipe will learn to stay away from cats. Similarly, the computers try things and interpret the results.

Mengdi Wang, an assistant professor of operations research and financial engineering, studies this approach. She has used reinforcement learning to limit risk in financial portfolios, help a local hospital predict complications in knee replacement surgery, and partner with Microsoft Research to produce story-quality dialogue.

One challenge when implementing reinforcement learning is data overload. Computers don't have the advantage of human forgetfulness, so they must process all incoming data. In practice, experts often have to step in to put some bounds on the number of items that need to be considered.

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

Barbara Engelhardt, associate professor of computer science, explores how a technique called reinforcement learning can guide physicians through difficult decisions such as when to remove a patient from a ventilator.

"Having too many variables is the bottleneck of reinforcement learning," Wang said. "Even if you have all the information in the world, you have a limited amount of processing power."

Wang developed a method for helping computers figure out what is and what is not important. It's an algorithm that reduces complexity by mathematically compressing a large collection of possible states into a small number of possible clusters. The approach, which she developed with Anru Zhang of the University of Wisconsin-Madison, uses statistics and optimization to group the likely scenarios for each stage of a decision-making process.

AI to the rescue

Although reinforcement learning is powerful, it offers no guarantees when an algorithm confronts a new environment. For example, an autonomous aerial vehicle (drone) trained to perform search-and-rescue missions in a certain set of environments may fail dramatically when deployed in a new one.

Developing approaches to guarantee drone safety and performance is the goal of Anirudha Majumdar, an assistant professor of mechanical and aerospace engineering. Due to safety and technological limitations, most drones today require a human to control the craft using its cameras and sensors. But steering drones through destroyed buildings, like those in the radioactivity-damaged Fukushima Daiichi power station in Japan, presents challenges.

Autonomous aerial vehicles could aid search-and-rescue efforts in tight spaces where the risk of human error is great. Majumdar is exploring how to apply a set of tools from machine learning known as "generalization theory" to guarantee drone safety in new environments. Roughly speaking, generalization theory provides ways to narrow the difference between performance on the training data and performance on new data.

Language learning

Teaching computers to recognize shapes is one thing, but teaching them to understand everyday language is quite another. To get at the question of how the brain processes language, Princeton researchers scanned the brains of volunteers who watched episodes of the BBC television series *Sherlock* to see what the brain is doing while its owner is taking in new information.

The challenge was how to aggregate results from several brains to identify trends. Each brain is shaped slightly differently, leading to slight differences in their functional magnetic resonance imaging (fMRI) scans. "It is as if you send a thousand tourists to take a photo of the Eiffel Tower. Each photo will be slightly different depending on the camera, the spot where the tourist stood to take the picture, and so forth," said Peter Ramadge, the Gordon Y.S. Wu Professor of Engineering and director of the Center for Statistics and Machine Learning. "You need machine learning to understand what is common to the response of all the subjects," he said.

Ramadge and other computer scientists, including then-undergraduate Kiran Vodrahalli of the Class of 2016, worked with researchers at the Princeton Neuroscience Institute to aggregate brain scans using a method for finding commonalities called a "shared response model." They then mapped brain activity to the dialogue in the episodes using a natural language processing technique — which extracts meaning from speech — developed by Sanjeev Arora, Princeton's Charles C. Fitzmorris Professor in Computer Science, and his team.

While a typical speech recognition method needs huge numbers of examples, the new method is capable of drawing meaning from a relatively small collection of words, such as the few hundred found in the script of the TV show. In a paper published in the journal *NeuroImage* in June 2017, the researchers demonstrated that they could determine from looking at the fMRI scans which scene was being watched with about 72 percent accuracy.

Into the black box

Machine learning has the potential to unlock questions that humans find difficult or impossible to answer, especially ones involving large data sets. For really complex questions, researchers have developed a method called deep learning, inspired by the human brain. This method relies on artificial neural networks, collections of artificial neurons that, like real brain cells, can receive a signal, process it, and produce an output to hand off to the next neuron.

While deep learning has been successful, researchers are still discovering what tasks it is best suited for, said Arora, who recently founded a program in theoretical machine learning at the nearby Institute for Advanced Study. "The field has derived a lot of use from treating deep learning as a black box," he said. "The question is what will we see when we open the black box."

Anirudha Majumdar, assistant professor of mechanical and aerospace engineering, uses machine learning to control autonomous aircraft, which can be deployed for search-and-rescue operations.

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

Efficient fusion reactions

To harness fusion — the same process that powers the sun — for our energy needs here on Earth, researchers at the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL) are using deep learning to predict factors that can halt fusion reactions and damage the walls of the containment vessel. William Tang, a PPPL physicist and a lecturer with the rank of professor in astrophysical sciences at Princeton, leads a team of researchers who are developing code for the massive international fusion experiment known as ITER (Latin for "the way"), under construction in France.
–By John Greenwald

Unintended consequences

In addition to broad ethical questions about the use of AI and the implications of intelligent machines in society, near-term worries about AI systems taking jobs from people are becoming more common. Enter Ed Felten, who is researching policies to curb the unintended consequences of AI.

Felten, the Robert E. Kahn Professor of Computer Science and Public Affairs and director of Princeton's Center for Information Technology Policy, served as deputy U.S. chief technology officer in the Obama White House, where he led federal policy initiatives on AI and machine learning.

With researchers at New York University, Felten has explored whether concerns about AI's impact on jobs and the economy can be supported by data. The researchers used standard benchmarks published by AI researchers. For visual recognition, for example, the team evaluated how many images an AI algorithm correctly categorized. Felten and his colleagues paired this estimation with data sets provided by the Bureau of Labor Statistics.

The question is whether AI will replace workers, or complement their efforts and lead to even greater opportunities? History shows that new technologies often prove beneficial for workers in the long term, but not without

Will AI disrupt low-skill workers? Not as much as you might think, according to Ed Felten, the Robert E. Kahn Professor of Computer Science and Public Affairs and director of the Center for Information Technology Policy.

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

Mengdi Wang, assistant professor of operations research and financial engineering, applies machine learning to subjects ranging from financial portfolios to storytelling.

short-term pains for workers replaced by technology.

While some researchers think that low-skill jobs will experience the greatest threat from artificially intelligent machines, Felten's numbers suggest otherwise. Airline pilots and lawyers may be at least as threatened by automation as the person behind the counter at the local 7-Eleven, he said.

"Things like house cleaning are very difficult to automate," Felten said. "The person doing that job needs to make a lot of contextual decisions. Which objects on the floor are trash and which objects on the floor are valued objects that have fallen on the floor?"

Felten and his team plan to pair their findings with geographic information, giving a kind of heat map on what regions of the country will be most affected, to allow companies and governments to prepare for the coming changes.

"I'm an optimist in that I think there's huge opportunity," Felten said. "AI is going to lead to tremendous progress in a lot of different areas. But it does come with risks, and we could easily do it badly."

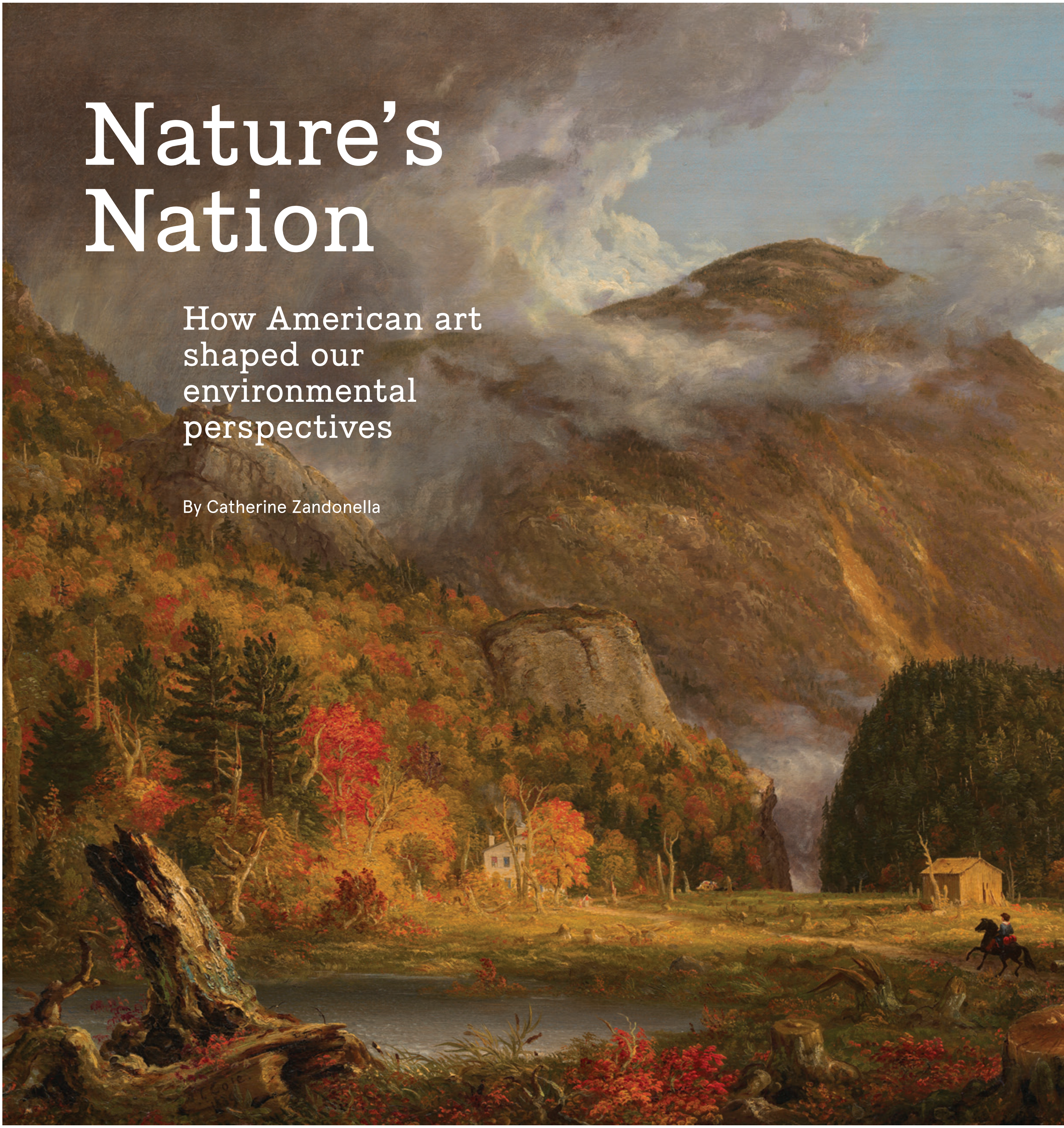
The future of chemistry

Machine learning can predict the outcomes of chemical reactions. Abigail Doyle, the A. Barton Hepburn Professor of Chemistry, and her team used a machine-learning technique called random forest analysis to obtain surprisingly accurate predictions of the yields of chemical reactions. A random forest model works by randomly selecting small samples from the training data set and using that sample to build a decision tree. Each individual decision tree then predicts the yield for a given reaction, and then the result is averaged across the trees to generate an overall yield prediction. The study was published in the journal *Science* in February 2018. **–By Liz Fuller-Wright**

Nature's Nation

How American art shaped our environmental perspectives

By Catherine Zandonella



OIL ON CANVAS, NATIONAL GALLERY OF ART, WASHINGTON

When landscape artist Thomas Cole visited New Hampshire's White Mountains in the summer of 1839, he sketched the telling signs of deforestation and human encroachment on a once pristine wilderness. But his final painting depicted a relatively unspoiled tableau, featuring rich forests and weather-blasted trunks.

Cole employed a bit of 19th-century photoshopping to edit out signs of development. He dialed up the scenic foliage and blurred the signs of human habitation — houses, barns, roads. His paintings spoke of a world where humans and nature could coexist.

Artists do more than reproduce the world around us. They also, for reasons from artistic to commercial to ideological, shape our perspective on the environment and our relationship with it.

The power of art to influence our understanding of the environment is the focus of a major new exhibition, *Nature's Nation: American Art and Environment*, which opened at the Princeton University Art Museum on Oct. 13, 2018. The exhibition brings together more than 100 pieces of American art to tell the story of ecological change in North America over 300 years of history.

Through the selection of works on display and an accompanying book, the exhibition addresses how artists in America have interpreted the environment over the centuries — from the era of exploration and colonialism through U.S. nationhood and expansion to the growing awareness of profound human impact on a global scale. The show also features recent artists whose work exposes environmental injustice and environmental change.

"We wanted to create an exhibition that would tell an alternative history of American art and chart the development of modern ecological consciousness — the understanding that nature is neither preordained nor immutable, but interconnected and fluid," said Karl Kusserow, the John Wilmerding Curator of American Art at the Princeton University Art Museum.

American landscape painter Thomas Cole covered up signs of development in his 1839 painting, *A View of the Mountain Pass Called the Notch of the White Mountains (Crawford Notch)*, as seen in comparison to a sketch he made earlier that year.

CRAWFORD NOTCH, GRAPHITE ON CREAM WOVE PAPER, PRINCETON UNIVERSITY ART MUSEUM

The exhibition's co-curator is Alan Braddock at the College of William and Mary, where he is the Ralph H. Wark Associate Professor of Art History and American Studies. He was also the Princeton Environmental Institute's Currie C. and Thomas A. Barron Visiting Professor in the Environment and the Humanities in 2016-17, as well as a Princeton Belknap Visiting Fellow in the Humanities Council in fall 2014.

"Artists have always made pictures of their world, but only in the last 300 years have we realized that humans are changing the world in significant and even unprecedented ways," said Braddock, who is a pioneer in the field known as ecocriticism, the study of the ecological significance of art, literature and other forms of expression.

"Art has the power to help us understand these issues and inform our ethical and moral decisions. It also alerts us to issues of environmental justice and ecological inequity, since not everyone perceives places and conditions in the same way."

Marketing colonialism

When European colonists arrived in North America, massive trees covered the land. Risks abounded, from swamps and new diseases to conflicts with indigenous peoples. Yet the continent was also bountiful with fish, game and timber.

Early works, published in the late 1500s to attract colonists, depicted the continent as a peaceful and orderly land just waiting to be colonized. Throughout the colonial period, the subjugation of the environment and its aboriginal population was rarely portrayed in works of art. Landscapes, when they did exist, appeared as the backgrounds of wealthy colonists' portraits and consisted of manicured gardens and serene vistas.

In *The Browning of America,* 2000, artist Jaune Quick-to-See Smith, a member of the Confederated Salish and Kootenai Tribes, reasserts the nation's indigenous presence.

OIL AND MIXED MEDIA ON CANVAS, CROCKER ART MUSEUM, SACRAMENTO ©JAUNE QUICK-TO-SEE SMITH

By the 1800s, however, American sentiment was changing. Many in the U.S. population, largely based in the Northeast, lamented the loss of wilderness, as documented in popular novels such as James Fenimore Cooper's 1826 novel, *The Last of the Mohicans*.

A painting style known as "picturesque," then popular in Europe and America, imposed order on wild nature while preserving its beauty. Artists placed rocks and trees in the foreground of the painting to give a sense of depth. The vistas unfurled in a logical, stepwise progression, with water bodies, promontories and mountains stretching into the distance.

American landscape painters, especially those in the group known as the Hudson River School because of their style and focus on upstate New York, embraced the picturesque. Long after the style grew out of fashion in Europe — replaced by a more realistic depiction of nature — it continued in the works of American artists, including in Western landscapes such as those by Thomas Moran, whose painting *The Grand Canyon of the Yellowstone* (see back cover) celebrated the nation's first national park in 1872 and was later used to attract tourists and settlers.

"Wilderness was seen as overwhelming, threatening and scary," Kusserow said. "To facilitate nation building in the 18th and 19th century, it was necessary to picture land as tractable and accessible to development."

Embodying the environment

Through their very materials, artistic works embody environments. The material origins of art can reveal the ecological and societal conditions of the past, said Laura Turner Igoe, an art historian who conducted investigations as part of the *Nature's Nation* exhibition while a postdoctoral researcher at Princeton.

One item Igoe examined, with help from materials scientists, was an 18th-century chest of drawers crafted in Philadelphia. Ornate and regal, the chest is made of mahogany from Jamaica, brass drawer pulls from England, American tulip poplar and white cedar framing, and varnish from North Africa.

The team determined that the mahogany had come from Jamaica in the mid-1700s, when European colonists used enslaved labor to clear forests and build sugar plantations.

"The construction of the chest implicates peoples and environments all over the globe, and through this analysis we were able to recover some of this lost history," Igoe said.

New beginnings

Art has the power to help us understand the environment — to take scientific data and turn it into "emotional data," said Rob Nixon, the Thomas A. and Currie C. Barron Family Professor in Humanities and the Environment and a professor of English and the Princeton Environmental Institute.

For *Nature's Nation*, Nixon explored a work by American photographer Chris Jordan, from the series *Midway: Message from the Gyre*, 2009. It is a photo of a decaying corpse of a baby albatross, its insides stuffed full with plastic bottle caps that its mother scooped up from the miles of floating detritus in the Great Pacific Garbage Patch and ladled into its hungry chick's beak. The image contrasts the revered values of nourishment and procreation against the practices of today's throwaway society.

Nixon said that images like these help the public make sense of complex issues like pollution, climate change, habitat loss and food security. "We constantly are faced with a cascade of data and metrics about the urgency of these issues," Nixon said, "but how do we translate and reconfigure these data in ways that reach people emotionally? I see that as very much germane to the spirit of this project."

Not just a nation

Nature's Nation, while set in the realm of American art, is not a uniquely American story. The United States is itself a planetary creation: Built with labor shipped across the sea, its colonies founded to supply natural resources, the country later became the world's consumer and continues to draw people from around the world. Borders cannot constrain the spread of pollution, climate change or endangered species.

Nor can borders contain human populations. *The Browning of America* is a work that illustrates the porosity of borders and reasserts the nation's indigenous presence through a mixed-media assemblage of symbols and collaged newspaper clippings covered with brownish-red stains. The work was created in 2000 by the artist Jaune Quick-to-See Smith, a member of the Confederated Salish and Kootenai Tribes.

Artists' interpretations of nature and nation have evolved since the days when Thomas Cole covered up human impacts on the environment. Kusserow and Braddock hope that by exposing the historical and present-day ways in which art imagines the environment, they can encourage the public conversation around issues of environmental preservation and justice.

ULTRACHROME INKJET PRINT. COLLECTION OF THE NEVADA MUSEUM OF ART. ©CHRIS JORDAN

In the photo series *Midway: Message from the Gyre*, 2009, Chris Jordan reveals the outcomes of today's throwaway society.

"This exhibition asks museum visitors to rethink some basic assumptions about who we are in the world," Kusserow said, "in a way that is designed to prompt conjecture and inspire, as well as teach." He realizes what a momentous task this is, and how high the stakes are.

"If you don't get them engaged, you've lost — we've lost."

After its premiere at Princeton (Oct. 13, 2018–Jan. 6, 2019), the exhibition travels to the Peabody Essex Museum in Salem, Massachusetts (Feb. 2–May 5, 2019), and to the Crystal Bridges Museum of American Art in Bentonville, Arkansas (May 25–Sept. 9, 2019).

Nature's Nation: American Art and Environment has been made possible with leadership support from Shelly Malkin, Class of 1986, and Tony Malkin; Annette Merle-Smith; the Henry Luce Foundation; the Princeton Environmental Institute; and the Barr Ferree Foundation Fund for Publications, Department of Art and Archaeology, Princeton University. Generous support has been provided by the National Endowment for the Arts Humanities Council, the Dean for Research Innovation Fund, and the Humanities Council's David A. Gardner '69 Magic Grant. Further support has been provided by Susan and John Diekman, Class of 1965; Gail and Peter Ochs, Class of 1965; the PSEG Foundation; the Kathleen C. Sherrerd Program Fund for American Art; Stacey Roth Goergen, Class of 1990, and Robert B. Goergen; the High Meadows Foundation Sustainability Fund; the New Jersey State Council on the Arts, a partner agency of the National Endowment for the Arts; the Program in American Studies, Princeton University; and the Partners and Friends of the Princeton University Art Museum. This exhibition is supported by an indemnity from the Federal Council on the Arts and the Humanities.

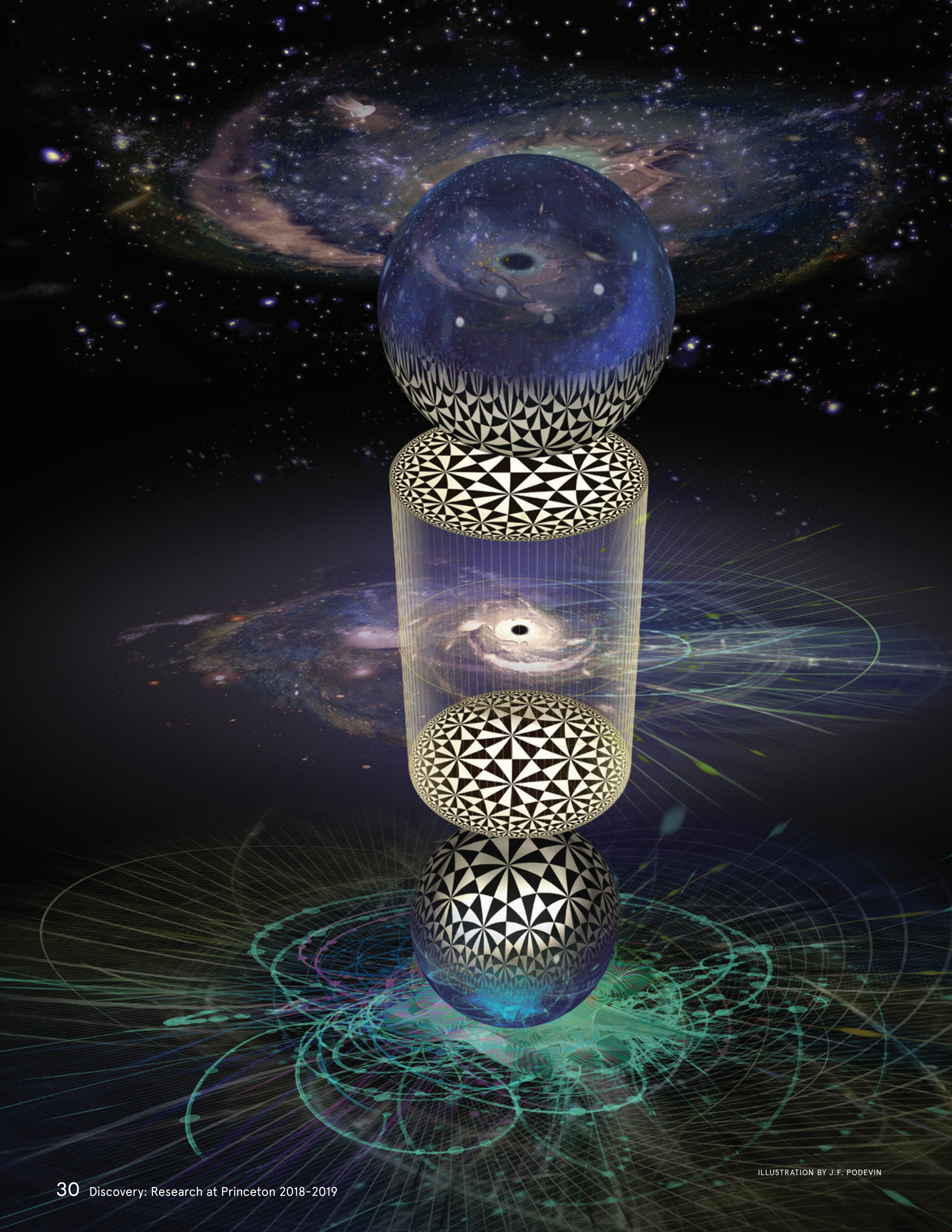


ILLUSTRATION BY J.F. PODEVIN

Beyond Einstein

Physicists find surprising connections in the cosmos

By Catherine Zandonella

Albert Einstein's desk can still be found on the second floor of Princeton's physics department. Positioned in front of a floor-to-ceiling blackboard covered with equations, the desk seems to embody the spirit of the frizzy-haired genius as he asks the department's current occupants, "So, have you solved it yet?"

Einstein never achieved his goal of a unified theory to explain the natural world in a single, coherent framework. Over the last century, researchers have pieced together links between three of the four known physical forces in a "standard model," but the fourth force, gravity, has always stood alone.

No longer. Thanks to insights made by Princeton faculty members and others who trained here, gravity is being brought in from the cold — although in a manner not remotely close to how Einstein had imagined it.

Though not yet a "theory of everything," this framework, laid down over 20 years ago and still being filled in, reveals surprising ways in which Einstein's theory of gravity relates to other areas of physics, giving researchers new tools with which to tackle elusive questions.

The key insight is that gravity, the force that brings baseballs back to Earth and governs the growth of black holes, is mathematically relatable to the peculiar antics of the subatomic particles that make up all the matter around us.

This revelation allows scientists to use one branch of physics to understand other seemingly unrelated areas of physics. So far, this concept has been applied to topics ranging from why black holes run a temperature to how a butterfly's beating wings can cause a storm on the other side of the world.

This relatability between gravity and subatomic particles provides a sort of Rosetta stone for physics. Ask a question about gravity, and you'll get an explanation couched in the terms of subatomic particles. And vice versa.

"This has turned out to be an incredibly rich area," said Igor Klebanov, Princeton's Eugene Higgins Professor of Physics, who generated some of the initial inklings in this field in the 1990s. "It lies at the intersection of many fields of physics."

From tiny bits of string

The seeds of this correspondence were sprinkled in the 1970s, when researchers were exploring tiny subatomic particles called quarks. These entities nest like Russian dolls inside protons, which in turn occupy the atoms that make up all matter. At the time, physicists found it odd that no matter how hard you smash two protons together, you cannot release the quarks — they stay confined inside the protons.

One person working on quark confinement was Alexander Polyakov, Princeton's Joseph Henry Professor of Physics. It turns out that quarks are "glued together" by other particles, called gluons. For a while, researchers thought gluons could assemble into strings that tie quarks to each other. Polyakov glimpsed a link between the theory of particles and the theory of strings, but the work was, in Polyakov's words, "hand-wavy" and he didn't have precise examples.

Meanwhile, the idea that fundamental particles are actually tiny bits of vibrating string was taking off, and by the mid-1980s, "string theory" had lassoed the imaginations of many leading physicists. The idea is simple: just as a vibrating violin string gives rise to different notes, each string's vibration foretells a particle's mass and behavior. The mathematical beauty was irresistible and led to a swell of enthusiasm for string theory as a way to explain not only particles but the universe itself.

A high standard

The standard model accounts for three of the four forces of nature: electromagnetism, which governs electricity, magnets and light; the strong force, which holds particles together inside the atomic nucleus;and the weak force, which acts over short distances and governs some forms of radioactivity.

At the atomic scale, objects follow a different set of physical laws from those that govern baseballs and cars. The laws of quantum mechanics lead to some quite odd behaviors. For example, two particles can have a long-distance connection such that measuring one affects its partner instantaneously, a state called "entanglement" that Einstein reluctantly embraced, calling it "spooky action at a distance."

One of Polyakov's colleagues was Klebanov, who in 1996 was an associate professor at Princeton, having earned his Ph.D. at Princeton a decade earlier. That year, Klebanov, with graduate student Steven Gubser and postdoctoral research associate Amanda Peet, used string theory to make calculations about gluons, and then compared their findings to a string-theory approach to understanding a black hole. They were surprised to find that both approaches yielded a very similar answer. A year later, Klebanov studied absorption rates by black holes and found that this time they agreed exactly.

That work was limited to the example of gluons and black holes. It took an insight by Juan Maldacena in 1997 to pull the pieces into a more general relationship. At that time, Maldacena, who had earned his Ph.D. at Princeton one year earlier, was an assistant professor at Harvard. He detected a correspondence between a special form of gravity and the theory that describes particles. Seeing the importance of Maldacena's conjecture, a Princeton team consisting of Gubser, Klebanov and Polyakov followed up with a related paper formulating the idea in more precise terms.

Another physicist who was immediately taken with the idea was Edward Witten of the Institute for Advanced Study (IAS), an independent research center located about a mile from the University campus. He wrote a paper that further formulated the idea, and the combination of the three papers in late 1997 and early 1998 opened the floodgates.

"It was a fundamentally new kind of connection," said Witten, a leader in the field of string theory who had earned his Ph.D. at Princeton in 1976 and is a visiting lecturer with the rank of professor in physics at Princeton. "Twenty years later, we haven't fully come to grips with it."

Two sides of the same coin

This relationship means that gravity and subatomic particle interactions are like two sides of the same coin. On one side is an extended version of gravity derived from Einstein's 1915 theory of general relativity. On the other side is the theory that roughly describes the behavior of subatomic particles and their interactions.

The latter theory includes the catalogue of particles and forces in the "standard model" (see sidebar), a framework to explain matter and its interactions that has survived rigorous testing in numerous experiments, including at the Large Hadron Collider.

The relationship between gravity and strings "was a fundamentally new kind of connection. Twenty years later, we haven't fully come to grips with it."

Edward Witten
Charles Simonyi Professor at the Institute for Advanced Study and Visiting Lecturer with the Rank of Professor in Physics at Princeton

ILLUSTRATION BY
J.F. PODEVIN

ILLUSTRATION BY
J.F. PODEVIN

"It is a tremendously successful idea. It compels one's attention. It ropes you in, it ropes in other fields, and it gives you a vantage point on theoretical physics that is very compelling."

Steven Gubser
Professor of Physics

In the standard model, quantum behaviors are baked in. Our world, when we get down to the level of particles, is a quantum world.

Notably absent from the standard model is gravity. Yet quantum behavior is at the basis of the other three forces, so why should gravity be immune?

The new framework brings gravity into the discussion. It is not exactly the gravity we know, but a slightly warped version that includes an extra dimension. The universe we know has four dimensions, the three that pinpoint an object in space — the height, width and depth of Einstein's desk, for example — plus the fourth dimension of time. The gravitational description adds a fifth dimension that causes spacetime to curve into a universe that includes copies of familiar four-dimensional flat space rescaled according to where they are found in the fifth dimension. This strange, curved spacetime is called anti-de Sitter (AdS) space after Einstein's collaborator, Dutch astronomer Willem de Sitter.

The breakthrough in the late 1990s was that mathematical calculations of the edge, or boundary, of this anti-de Sitter space can be applied to problems involving quantum behaviors of subatomic particles described by a mathematical relationship called conformal field theory (CFT). This relationship provides the link, which Polyakov had glimpsed earlier, between the theory of particles in four spacetime dimensions and string theory in five dimensions. The relationship now goes by several names that relate gravity to particles, but most researchers call it the AdS/CFT (pronounced A-D-S-C-F-T) correspondence.

Tackling the big questions

This correspondence, it turns out, has many practical uses. Take black holes, for example. The late physicist Stephen Hawking startled the physics community by discovering that black holes have a temperature that arises because each particle that falls into a black hole has an entangled particle that can escape as heat. Using AdS/CFT, Tadashi Takayanagi and Shinsei Ryu, then at the University of California-Santa Barbara, discovered a new way to study entanglement in terms of geometry, extending Hawking's insights in a fashion that experts consider quite remarkable.

In another example, researchers are using AdS/CFT to pin down chaos theory, which says that a random and insignificant event such as the flapping of a butterfly's wings could result in massive changes to a large-scale system such as a faraway hurricane. It is difficult to calculate chaos, but black holes — which are some of the most chaotic quantum systems possible — could help. Work by Stephen Shenker and Douglas Stanford at Stanford University, along with Maldacena, demonstrates how, through AdS/CFT, black holes can model quantum chaos.

One open question Maldacena hopes the AdS/CFT correspondence will answer is the question of what it is like inside a black hole, where an infinitely dense region called a singularity resides. So far, the relationship gives us a picture of the black hole as seen from the outside, said Maldacena, who is now the Carl P. Feinberg Professor at IAS.

"We hope to understand the singularity inside the black hole," Maldacena said. "Understanding this would probably lead to interesting lessons for the Big Bang."

The relationship between gravity and strings has also shed new light on quark confinement, initially through work by Polyakov and Witten, and later by Klebanov and Matt Strassler, who was then at IAS.

Those are just a few examples of how the relationship can be used. "It is a tremendously successful idea," said Steven Gubser, who today is a professor of physics at Princeton. "It compels one's attention. It ropes you in, it ropes in other fields, and it gives you a vantage point on theoretical physics that is very compelling."

The relationship may even unlock the quantum nature of gravity. "It is among our best clues to understand gravity from a quantum perspective," said Witten. "Since we don't know what is still missing, I cannot tell you how big a piece of the picture it ultimately will be."

Still, the AdS/CFT correspondence, while powerful, relies on a simplified version of spacetime that is not exactly like the real universe. Researchers are working to find ways to make the theory more broadly applicable to the everyday world, including Gubser's research on modeling the collisions of heavy ions, as well as high-temperature superconductors.

Also on the to-do list is developing a proof of this correspondence that draws on underlying physical principles. It is unlikely that Einstein would be satisfied without a proof, said Herman Verlinde, Princeton's Class of 1909 Professor of Physics, the chair of the Department of Physics and an expert in string theory, who shares office space with Einstein's desk.

"Sometimes I imagine he is still sitting there," Verlinde said, "and I wonder what he would think of our progress."

Fact-checking Immigration

Professor Leah Boustan uses big data to explore myths about the past

By Kevin McElwee

PHOTO FROM THINKSTOCK BY GETTY IMAGES

PHOTO BY EDWIN LEVICK COURTESY OF THE LIBRARY OF CONGRESS.

Leah Boustan, professor of economics, uses digitized historical records and other sources — like this 1906 photograph of immigrants on an Atlantic liner — to give researchers a statistical footing for studies on immigration, past and present.

"When the horns started to blow and we saw the Statue of Liberty, I thought I was in heaven. Really. She's up there and saying, 'Come on in. From now on you are a free person.'"

These are the words of Turkish immigrant John Alabilikian, who came to the United States in 1922, collected by the Ellis Island Foundation in 1985 as part of its oral history library. In his interview, Alabilikian described escaping the Armenian genocide and journeying to America.

Personal anecdotes like these serve as a rich source of data for economist Leah Platt Boustan, who brings modern statistical analysis and big-data tools to the study of historical events and trends. With the recent digitization of first-person accounts and other documents, Boustan can uncover insights from people's personal experiences in ways previously not possible. "It's almost as if we can conduct surveys of people who lived in the past," she said.

Boustan, who joined Princeton as a professor in economics in 2017, has an impressive record of proving and disproving ideas that people believe based on anecdotes or "gut feelings." In the past, economists and historians had few data tools, but with today's powerful computers and mathematical approaches, historical perspectives can be tested against hard numbers.

"Often what we think we know, we don't really know," Boustan said. "If you start to introspect, and ask, 'Where do my beliefs come from?' you might realize they come from your family's experience or from relatively few anecdotes. We rarely test our beliefs with thousands of cases." Boustan tries to rediscover that lost nuance, giving economists and historians a statistical footing for their research.

One of the questions Boustan has tackled is the issue of "white flight." Between 1940 and 1970, white Americans left cities in large numbers, but historians have debated whether this exodus was motivated by the desire to pursue opportunities in suburbs or because of an influx of black Americans. Boustan's analysis, published in the *Quarterly Journal of Economics* in 2010 when she was on the faculty at the University of California-Los Angeles, suggests that both were true.

Another of Boustan's recent projects is on the age of mass migration, a period from around 1850 to about 1920, when more than 30 million Europeans moved to the United States. Working with longtime collaborators Ran Abramitzky at Stanford University and Katherine Eriksson at the University of California-Davis, and with support from the National Science Foundation, Boustan compared historical data to today's records, asking: Are immigrants today assimilating more slowly than they did in the past?

"Many people imagine that immigrants from Europe very quickly climbed the economic ladder and adopted U.S. behavior norms, and that immigrants today are slower to do so," Boustan said. "That's not the case."

Prior work suggested that European immigrants during the age of mass migration were paid less than native-born workers upon first arrival, but then quickly caught up. Boustan and her collaborators tracked the occupations of 21,000 natives and immigrants over two decades, and, in work published in 2014 in the *Journal of Political Economy*, showed that this common wisdom does not fit the facts in two different ways. Many recently arrived immigrant groups did not have lower earnings than natives and, overall, the income of immigrants and natives rose at close to the same rate.

Slow rates of economic assimilation are consistent with the experiences of recent immigrants, according to studies by other researchers, Boustan said. "There is nothing special — or necessarily alarming — about economic convergence that takes more than one generation," Boustan said. "We have been there before."

One measure of cultural assimilation that Boustan looked at was how immigrants named their children. Because selecting a child's name costs nothing, and thus is independent of socio-economic status, Boustan argued that names indicate a family's eagerness to adopt American culture. In work supported by a grant from the Russell Sage Foundation, she and her colleagues used millions of entries from recently digitized census records to calculate a "foreignness index" for each name in the early 1900s. She conducted a similar exercise using birth certificate records from California today. In both cases, she found that immigrants shift away from foreign-sounding names as they spend more time in their adopted nation, and at the same rate.

"What was striking about those two sets of analyses — the past and present — is that the speed of cultural assimilation, by this measure, is almost identical in the past and present," Boustan said. The study is detailed in an NBER Working Paper posted in July 2016.

Boustan's work is part of a growing trend in economics toward harnessing large data sets to explain historical observations, said her colleague and former mentor, Henry Farber, Princeton's Hughes-Rogers Professor of Economics. Farber met Boustan when she was an undergraduate at Princeton in the late 1990s. Boustan later earned a Ph.D. at Harvard University in 2006 and then became a professor at the University of California-Los Angeles.

Today, Boustan's office is only a few doors down from Farber, who is next door to his own dissertation adviser, Orley Ashenfelter, the Joseph Douglas Green 1895 Professor of Economics — three generations of empirical economics in one hallway. "Princeton is lucky to have her on the faculty," Farber said.

Boustan is also part of the trend toward increasing female participation in a historically male-dominated discipline. When a leading journal recently asked her how the field might attract and train more women, she was caught off guard. "I realized that I didn't know much about the overall situation of women in economics — I only knew anecdotes from my personal experiences," Boustan said.

So she began investigating the problem with her characteristic big-data approach. "It is a very important question, and the best way to work on big questions is to take a look at the data," she said.

She paired with graduate student Andrew Langan to collect data on the male-female graduate student ratios in economics departments at leading research universities and learn more about why some programs have more success than others in training women. Graduate programs in economics are on average 30 percent female across the nation, with some as low as 10 percent female and others achieving a 50-50 balance, Boustan and her team found.

"The average picture looks gloomy, but there are some bright rays," Boustan said. For example, even departments with high numbers of male students and faculty can serve female students well if they provide opportunities for training and mentoring, they found.

Boustan keeps this in mind as she mentors and advises students in Princeton's economics department. One advisee, Ji Won Choi, said, "I hope I can be an example, like Leah, for others in the future."

Until recently, Princeton's Department of Economics had few women in senior faculty positions, but the department has doubled its number of female faculty members over the past four years, said Janet Currie, the Henry Putnam Professor of Economics and Public Affairs at the Woodrow Wilson School, who was department chair until June 2018. "Nevertheless," Currie said, "we are not where we would like to be, and we'll need continuous effort not to lose the gains we have made and to diversify the faculty and student body in other dimensions."

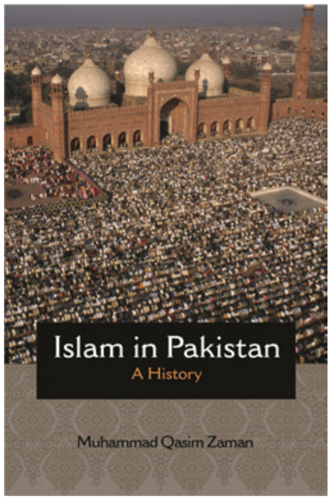
With so many charged topics facing society today, from the equitable treatment of women in the workplace to the role of immigrants in building the nation, Boustan's data-driven approach to controversial issues is more relevant than ever. To explain the importance of this work, Boustan quotes her former mentor, the Harvard economic historian and labor economist Claudia Goldin: "The best historical questions are the ones that speak to the world we live in today."

“Many people imagine that [19th-century] immigrants from Europe very quickly climbed the economic ladder and adopted U.S. behavior norms, and that immigrants today are slower to do so. That’s not the case.”

Leah Boustan
Professor of Economics

PHOTO BY DAVID KELLY CROW

Books



Islam in Pakistan: ***A History***

Princeton University Press, May 2018

Muhammad Qasim Zaman, the Robert H. Niehaus '77 Professor of Near Eastern Studies and Religion

The first modern state to be founded in the name of Islam, Pakistan was the largest Muslim country in the world at the time of its establishment in 1947. *Islam in Pakistan* is the first comprehensive book to explore Islam's evolution in this region over the past century and a half, from the British colonial era to the present day.

Muhammad Qasim Zaman presents a rich historical account of this major Muslim nation, insights into the rise and gradual decline of Islamic modernist thought in the South Asian region, and an understanding of how Islam has fared in the contemporary world. Examining how facets of Islam have been pivotal in Pakistani history, *Islam in Pakistan* offers sweeping perspectives on what constitutes an Islamic state.

The Dancing Lares and the Serpent in the Garden:

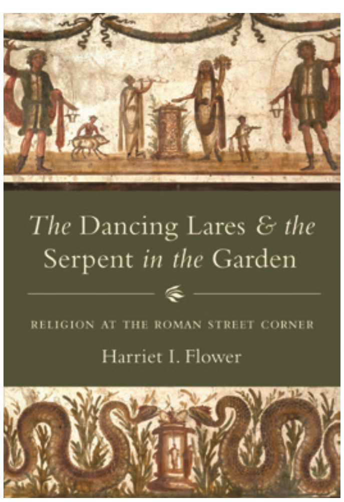
Religion at the Roman Street Corner

Princeton University Press, September 2017

Harriet Flower, the Andrew Fleming West Professor in Classics

The most pervasive gods in ancient Rome had no traditional mythology attached to them, nor was their worship organized by elites. Throughout the Roman world, neighborhood street corners, farm boundaries and household hearths featured small shrines to the beloved lares, a pair of cheerful little dancing gods. These shrines were maintained primarily by ordinary Romans, and often by slaves and freedmen, for whom the lares' cult provided a unique public leadership role. In this comprehensive and richly illustrated book, the first to focus on the lares, Harriet Flower offers a strikingly original account of these gods and a new way of understanding the lived experience of everyday Roman religion.

A reconsideration of seemingly humble gods that were central to the religious world of the Romans, this is also the first major account of the full range of lares worship in the homes, neighborhoods and temples of ancient Rome.

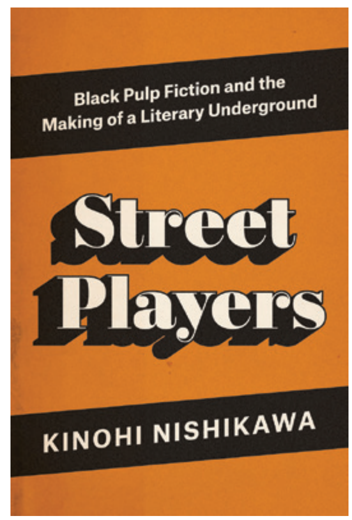


Street Players:

Black Pulp Fiction and the Making of a Literary Underground

University of Chicago Press, November 2018

Kinohi Nishikawa, assistant professor of English and African American studies



The uncontested center of the black pulp fiction universe for more than four decades was Los Angeles publisher Holloway House. From the late 1960s until it closed in 2008, Holloway House specialized in cheap paperbacks with page-turning narratives featuring black protagonists in crime stories, conspiracy thrillers, prison novels and Westerns.

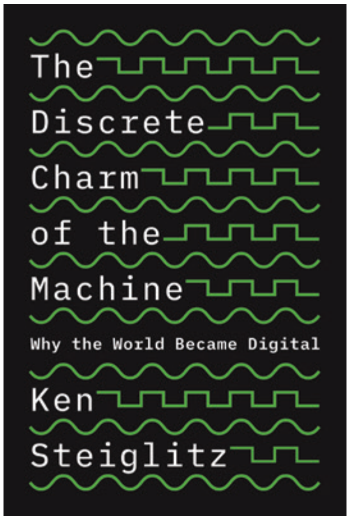
Kinohi Nishikawa contends that black pulp fiction was built on white readers' fears of the feminization of society — and the appeal of black masculinity as a way to counter it. In essence, it was the original blaxploitation: mass-marketing race to suit the reactionary fantasies of a white audience. But while chauvinism and misogyny remained troubling yet constitutive aspects of this literature, after 1972 Holloway House moved away from publishing sleaze for a white audience to publishing solely for black readers.

When it closed, Holloway House was synonymous with genre fiction written by black authors for black readers — a field of cultural production that Nishikawa terms "the black literary underground." But as *Street Players* demonstrates, this cultural authenticity had to be promoted and in some cases made up — and there is a story of exploitation at the heart of black pulp fiction's origins that cannot be ignored.

The Discrete Charm of the Machine:

Why the World Became Digital

Princeton University Press, forthcoming February 2019



Ken Steiglitz, the Eugene Higgins Professor of Computer Science, Emeritus, and senior scholar

A few short decades ago, we were informed by the smooth signals of analog television, radio and vinyl discs; communicated with our analog telephones; and even computed with analog computers. Today our world is digital, built with zeros and ones. Why did this revolution occur?

The Discrete Charm of the Machine explains, in an engaging and accessible manner, the varied physical and logical reasons behind this radical transformation. The spark of individual genius shines through this story of innovation: the stored program of Jacquard's loom, the logical branching of Charles Babbage, Alan Turing's brilliant abstraction of the discrete machine. Steiglitz follows the progression of these ideas in the building of our digital world, from the internet and artificial intelligence to the edge of the unknown.

The Chinese Must Go:

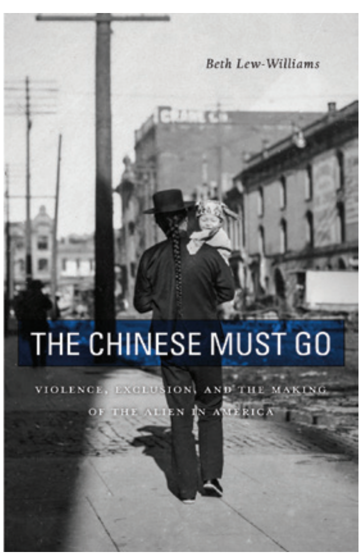
Violence, Exclusion, and the Making of the Alien in America

Harvard University Press, February 2018

Beth Lew-Williams, assistant professor of history

The American West erupted in anti-Chinese violence in 1885. Following the massacre of Chinese miners in Wyoming Territory, communities throughout California and the Pacific Northwest harassed, assaulted and expelled thousands of Chinese immigrants. Beth Lew-Williams shows how American immigration policies incited this violence and how the violence, in turn, provoked new exclusionary policies. Ultimately, Lew-Williams argues, Chinese expulsion and exclusion produced the concept of the "alien" in modern America.

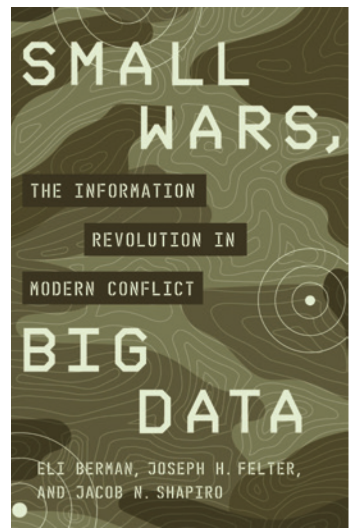
As *The Chinese Must Go* makes clear, anti-Chinese law and violence continues to have consequences for today's immigrants. The present resurgence of xenophobia builds mightily upon past fears of the "heathen Chinaman."



Small Wars, Big Data:

The Information Revolution in Modern Conflict

Princeton University Press, June 2018



Eli Berman, chair of economics at the University of California-San Diego
Joseph Felter, deputy assistant secretary of defense for South and Southeast Asia
Jacob Shapiro, professor of politics and international affairs at Princeton's Woodrow Wilson School of Public and International Affairs
with **Vestal McIntyre**, staff writer at the Harvard Kennedy School

The way wars are fought has changed starkly over the past 60 years. International military campaigns used to play out between large armies at central fronts. Today's conflicts find major powers facing rebel insurgencies that deploy elusive methods, from improvised explosives to terrorist attacks. *Small Wars, Big Data* presents a transformative understanding of these contemporary confrontations and how they should be fought. The authors show that a revolution in the study of conflict — enabled by vast data, rich qualitative evidence and modern methods — yields new insights into terrorism, civil wars and foreign interventions.

Modern warfare is not about struggles over territory but over people. Civilians — and the information they might choose to provide — can turn the tide at critical junctures. *Small Wars, Big Data* provides groundbreaking perspectives for how small wars can be better strategized and won to the benefit of the local population.

Selected Faculty Honors

Memberships and Fellowships

American Academy of Arts and Letters: Member

Jeffrey Eugenides, professor of creative writing in the Lewis Center for the Arts (2018)

American Academy of Arts and Sciences: Member

Simon Gikandi, Robert Schirmer Professor of English; chair, Department of English (2018)

Daniel Heller-Roazen, Arthur W. Marks '19 Professor of Comparative Literature (2018)

Tali Mendelberg, John Work Garrett Professor in Politics (2018)

Jacqueline Stone, professor of religion (2018)

American Council of Learned Societies: Fellow

Thomas Conlan, professor of East Asian studies and history (2018)

Katja Guenther, associate professor of history (2018)

American Mathematical Society: Fellow

Fernando Codá Marques, professor of mathematics (2018)

Alexandru Ionescu, professor of mathematics (2018)

Sergiu Klainerman, Eugene Higgins Professor of Mathematics (2018)

John Pardon, professor of mathematics (2018)

Peter Sarnak, Eugene Higgins Professor of Mathematics (2018)

Association for Computing Machinery: Fellow

Aarti Gupta, professor of computer science (2017)

Combustion Institute: Fellow

Frederick Dryer, professor of mechanical and aerospace engineering, emeritus; senior scholar (2018)

Irvin Glassman, Robert H. Goddard Professor of Mechanical and Aerospace Engineering, Emeritus (2018)

Yiguang Ju, Robert Porter Patterson Professor of Mechanical and Aerospace Engineering (2018)

Chung Law, Robert H. Goddard Professor of Mechanical and Aerospace Engineering (2018)

Engineering professors named fellows of National Academy of Inventors

Two engineering faculty members, Paul Prucnal and Jennifer Rexford, have been named as fellows of the National Academy of Inventors, an honor that recognizes contributions that have an impact on quality of life, economic development and societal welfare.

Prucnal, a professor of electrical engineering, is recognized as the inventor of an ultra-fast switch called the Terahertz Optical Asymmetric Demultiplexer. Prucnal's research concentrates on optical communications and signal processing. His research into optical networks in the 1980s generated new disciplines in the field and has resulted in over 1,000 scholarly papers. Prucnal is the holder of 27 patents.

Rexford, chair of computer science and the Gordon Y.S. Wu Professor in Engineering, is an expert on large computer networks and internet routing. She has made several contributions to the development of the Border Gateway Protocol, which allows for communications among the many networks that form the internet. A 1991 alumna, Rexford holds 22 patents.

–By John Sullivan

PHOTOS BY DAVID KELLY CROW

Paul Prucnal

Jennifer Rexford

Clifford Brangwynne selected as Howard Hughes Medical Institute Investigator

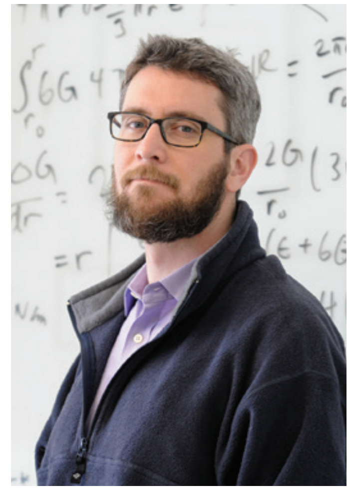
Clifford Brangwynne, whose research explores the hidden order within cellular liquid, has been named a Howard Hughes Medical Institute Investigator.

Brangwynne, an associate professor of chemical and biological engineering at Princeton University, is one of 19 new investigators named by the institute this year. The distinction is one of the most sought-after awards in biomedical research.

A nonprofit medical research organization headquartered in Chevy Chase, Maryland, HHMI provides roughly $8 million over a seven-year period for researchers, who remain based at their home institutions, pursuing cutting-edge science. This innovative approach affords researchers time to concentrate on their work and not have to continually seek short-term grants.

–By Adam Hadhazy

PHOTO BY LAURA PEDRICK FOR HHMI



Clifford Brangwynne

Dorothy and Lewis B. Cullman Center for Scholars and Writers: Fellow

Brooke Holmes, Robert F. Goheen Professor in the Humanities, professor of classics (2018)

Dorothy and Lewis B. Cullman Center for Scholars and Writers: John and Constance Birkelund Fellow

David Bell, Sidney and Ruth Lapidus Professor in the Era of North Atlantic Revolutions, professor of history (2018)

Econometric Society: Fellow

Esteban Rossi-Hansberg, Theodore A. Wells ’29 Professor of Economics and International Affairs (2017)

Leeat Yariv, Uwe Reinhardt Professor of Economics (2017)

ITER: Science Fellow

David Johnson, principal research physicist, Princeton Plasma Physics Laboratory (2018)

Francesca Poli, research physicist, Princeton Plasma Physics Laboratory (2017)

Charles Skinner, principal research physicist, Princeton Plasma Physics Laboratory (2018)

John D. and Catherine T. MacArthur Foundation: Fellow

Elizabeth Paluck, professor of psychology and public affairs (2017)

National Academy of Design: National Academician

Eve Aschheim, lecturer in visual arts and the Lewis Center for the Arts (2017)

National Academy of Medicine: Member

Anne Case, Alexander Stewart 1886 Professor of Economics and Public Affairs, Emeritus (2017)

National Academy of Sciences: Member

Sanjeev Arora, Charles C. Fitzmorris Professor in Computer Science (2018)

Orley Ashenfelter, Joseph Douglas Green 1895 Professor of Economics (2018)

Dalton Conley, Henry Putnam University Professor in Sociology (2018)

David MacMillan, James S. McDonnell Distinguished University Professor of Chemistry (2018)

Peter Ozsváth, professor of mathematics (2018)

Virginia Zakian, Harry C. Wiess Professor in the Life Sciences, professor of molecular biology (2018)

National Distinctions for Early Career Researchers

Alfred P. Sloan Foundation: Research Fellowship

Todd Hyster, assistant professor of chemistry (2018)

Mary Caswell Stoddard, assistant professor of ecology and evolutionary biology (2018)

Camille and Henry Dreyfus Foundation: Camille Dreyfus Teacher-Scholar

Mohammad Seyedsayamdost, assistant professor of chemistry (2018)

David and Lucile Packard Foundation: Packard Fellowship for Science and Engineering

John Pardon, professor of mathematics (2017)

Defense Advanced Research Projects Agency: Young Faculty Award

Amir Ali Ahmadi, assistant professor of operations research and financial engineering (2017)

Nathalie de Leon, assistant professor of electrical engineering (2018)

Kaushik Sengupta, assistant professor of electrical engineering (2018)

National Science Foundation: Early Career Development (CAREER) Award

José Avalos, assistant professor of chemical and biological engineering and the Andlinger Center for Energy and the Environment (2018)

Ian Bourg, assistant professor of civil and environmental engineering and the Princeton Environmental Institute (2018)

Nathalie de Leon, assistant professor of electrical engineering (2018)

Barbara Engelhardt, associate professor of computer science (2018)

Gillat Kol, assistant professor of computer science (2018)

Andrej Kosmrlj, assistant professor of mechanical and aerospace engineering (2017)

Wyatt Lloyd, assistant professor of computer science (2017)

Jared Toettcher, assistant professor of molecular biology, James A. Elkins, Jr. '41 Preceptor in Molecular Biology (2018)

Mark Zhandry, assistant professor of computer science (2018)

U.S. Air Force Office of Scientific Research: Young Investigator Research Program Award

Jeffrey Thompson, assistant professor of electrical engineering (2017)

U.S. Department of Energy Office of Science: Early Career Research Program Award

Nathalie de Leon, assistant professor of electrical engineering (2018)

Nathaniel Ferraro, theoretical/computational research physicist, Princeton Plasma Physics Laboratory (2018)

Samuel Lazerson, research physicist, Princeton Plasma Physics Laboratory (2018)

U.S. Office of Naval Research: Young Investigator Program Award

Prateek Mittal, associate professor of electrical engineering (2018)

Tera Hunter earns awards for scholarship on slave marriage

Tera Hunter, the Edwards Professor of American History and a professor of history and African American studies, received three prizes for her 2017 book, *Bound in Wedlock: Slave and Free Black Marriage in the Nineteenth Century*.

The Organization of American Historians awarded her the Mary Nickliss Prize in U.S. Women's and/or Gender History, and the American Historical Association gave her two awards, the Joan Kelly Memorial Prize (for women's history and/or feminist theory) and the Littleton-Griswold Prize (in U.S. law and society).

Hunter researched court records, legal documents and personal diaries to illustrate the constraints that slavery placed on intimate relationships. Her own great-great-grandparents, Ellen and Moses Hunter, were enslaved, freed and then married during Reconstruction. **–By Denise Valenti**

PHOTO COURTESY OF THE DEPARTMENT OF AFRICAN AMERICAN STUDIES

Tera Hunter

Prizes and Distinctions

American Astronomical Society's Division on Dynamical Astronomy

James Stone, Lyman Spitzer Jr., Professor of Theoretical Astrophysics; professor of astrophysical sciences and applied and computational mathematics; chair, Department of Astrophysical Sciences: **2018 Brouwer Award**

American Chemical Society

Emily Carter, dean, School of Engineering and Applied Science; Gerhard R. Andlinger Professor in Energy and the Environment; professor of mechanical and aerospace engineering and applied and computational mathematics: **2018 Award in Theoretical Chemistry**

David MacMillan, James S. McDonnell Distinguished University Professor of Chemistry: **2018 Gabor A. Somorjai Award for Creative Research in Catalysis**

American Geophysical Union

Eric Wood, Susan Dod Brown Professor of Civil and Environmental Engineering: **2017 Robert E. Horton Medal**

American Historical Association

Matthew Karp, assistant professor of history, Elias Boudinot Bicentennial Preceptor: **2017 John H. Dunning Prize**

American Philosophical Society

Angela Creager, Thomas M. Siebel Professor in the History of Science, professor of history: **2018 Patrick Suppes Prize in the History of Science**

Douglas Massey, Henry G. Bryant Professor of Sociology and Public Affairs, Woodrow Wilson School: **2017 Henry Allen Moe Prize in the Humanities**

American Physical Society

William Bialek, John Archibald Wheeler/Battelle Professor in Physics and the Lewis-Sigler Institute for Integrative Genomics: **2018 Max Delbrück Prize in Biological Physics**

American Political Science Association

Paul Frymer, professor of politics: **2018 J. David Greenstone Book Prize**

Alisha Holland, assistant professor of politics: **2018 Giovanni Sartori Book Award**

American Society for Matrix Biology

Jean Schwarzbauer, Eugene Higgins Professor of Molecular Biology: **2018 Senior Investigator Award**

American Society of Civil Engineers

Sigrid Adriaenssens, associate professor of civil and environmental engineering: **2018 George Winter Award**

American Statistical Association

Jianqing Fan, Frederick L. Moore, Class of 1918, Professor in Finance; professor of operations research and financial engineering: **2018 Noether Senior Scholar Award**

Association for Computer Aided Design in Architecture

Mónica Ponce de León, dean, School of Architecture; professor of architecture: **2018 Teaching Award of Excellence**

Association for Computing Machinery

Kyle Jamieson, associate professor of computer science: **2018 SIGMOBILE RockStar Award**

Stephen Lyon, professor of electrical engineering: **2017 SenSys Test of Time Award**

Margaret Martonosi, Hugh Trumbull Adams '35 Professor of Computer Science: **2017 SenSys Test of Time Award**

Jennifer Rexford, Gordon Y.S. Wu Professor in Engineering; professor of computer science; chair, Department of Computer Science: **2018 SIGCOMM Award**

Association for Psychological Science

Jonathan Cohen, Robert Bendheim and Lynn Bendheim Thoman Professor in Neuroscience; professor of psychology and the Princeton Neuroscience Institute: **2018 William James Fellow Award**

Brain & Behavior Research Foundation

Ilana Witten, associate professor of psychology and the Princeton Neuroscience Institute: **2017 Freedman Prize for Exceptional Basic Research**

Breakthrough Prize Foundation

Jo Dunkley, professor of physics and astrophysical sciences: **2018 Breakthrough Prize in Fundamental Physics, as part of the WMAP Science Team**

Norman Jarosik, senior research physicist, lecturer in physics: **2018 Breakthrough Prize in Fundamental Physics**

Lyman Page Jr., James S. McDonnell Distinguished University Professor in Physics: **2018 Breakthrough Prize in Fundamental Physics**

David Spergel, Charles A. Young Professor of Astronomy on the Class of 1897 Foundation, professor of astrophysical sciences: **2018 Breakthrough Prize in Fundamental Physics**

Econometric Society

Stephen Redding, Harold T. Shapiro '64 Professor in Economics; professor of economics and international affairs, Woodrow Wilson School: **2018 Frisch Medal**

Fusion Power Associates

Steven Cowley, director, Princeton Plasma Physics Laboratory, professor of astrophysical sciences: **2017 Distinguished Career Award**

Nathaniel Fisch, professor of astrophysical sciences: **2018 Distinguished Career Award**

Stewart Prager, professor of astrophysical sciences: **2017 Distinguished Career Award**

Gruber Foundation

Jo Dunkley, professor of physics and astrophysical sciences: **2018 Cosmology Prize as part of the Planck Team**

William Jones, associate professor of physics: **2018 Cosmology Prize as part of the Planck Team**

IEEE

Bede Liu, professor of electrical engineering, emeritus: **2018 Jack S. Kilby Signal Processing Medal**

Margaret Martonosi, Hugh Trumbull Adams '35 Professor of Computer Science: **2018 Technical Achievement Award**

INFORMS Optimization Society

Robert Vanderbei, professor of operations research and financial engineering: **2017 Khachiyan Prize**

Four Princeton faculty members win Guggenheim Fellowships

Four Princeton faculty members, representing a range of subjects in the humanities, have received Guggenheim Fellowships.

Brooke Holmes, the Robert F. Goheen Professor in the Humanities and professor of classics, explores the Greco-Roman roots of Western ideas about the physical body, the natural world, matter and the non-human.

Martin Kern, the Greg ('84) and Joanna (P13) Zeluck Professor in Asian Studies and chair of the East Asian studies department, was awarded the Guggenheim for his project *Performance, Memory and Authorship in Ancient China: The Formation of the Poetic Tradition*.

Ekaterina Pravilova, professor of history, specializes in 19th-century Imperial Russia, and was awarded the Guggenheim for her project *Political Money: A History of the Russian Ruble, 1768-1917*.

Monica Youn, a lecturer in creative writing and the Lewis Center for the Arts, is the author of three books of poetry, most recently *Blackacre* (2016), which won the William Carlos Williams Award of the Poetry Society of America. Her 2010 book, *Ignatz*, was a finalist for the National Book Award.
–By the Office of Communications

PHOTO BY DENISE APPLEWHITE

Ekaterina Pravilova

PHOTO COURTESY OF THE OFFICE OF ADMISSION

Brooke Holmes

PHOTO BY ADENA STEVENS

Martin Kern

PHOTO COURTESY OF MONICA YOUN

Monica Youn

Jewish Book Council

Eve Krakowski, assistant professor of Near Eastern studies and Program in Judaic Studies, Christian Gauss Fund University Preceptor: **2017 National Jewish Book Award**

Yair Mintzker, professor of history: **2017 National Jewish Book Award**

Journal of Africana Religions

Judith Weisenfeld, Agate Brown and George L. Collord Professor of Religion: **2017 Albert J. Raboteau Prize for the Best Book in Africana Religions**

PHOTO BY DENISE APPLEWHITE

Paul Muldoon

Paul Muldoon receives Her Majesty's Gold Medal for Poetry from Queen Elizabeth

Paul Muldoon, the Howard G.B. Clark '21 University Professor in the Humanities, professor of creative writing in the Lewis Center for the Arts and director of the Princeton Atelier, has received Her Majesty's Gold Medal for Poetry.

Muldoon, a native of Ireland, is the second Irish poet to receive the award in its 83-year history, after Michael Longley in 2001. The Poetry Medal Committee recommended Muldoon on the basis of the body of his work. Dame Carol Ann Duffy, Britain's poet laureate, described his work as "ambitious, erudite, witty and musical." **–By Jamie Saxon**

Materials Research Society

Sigurd Wagner, professor of electrical engineering, emeritus; senior scholar: **2017 David Turnbull Lectureship Award**

Modern Language Association

Christy Wampole, associate professor of French and Italian: **2017 Prize for a First Book**

National Book Critics Circle

John McPhee, Ferris Professor of Journalism in Residence: **2018 Sandhof Award for Lifetime Achievement**

National Endowment for the Humanities

Judith Weisenfeld, Agate Brown and George L. Collord Professor of Religion: **2017 Fellowship**

New York State

Alicia Ostriker, lecturer with the rank of professor in creative writing and the Lewis Center for the Arts: **2018 New York State Poet, New York State Walt Whitman Citation of Merit for Poets**

Nokia Corporation

Kaushik Sengupta, assistant professor of electrical engineering: **2017 Bell Labs Prize**

Northwestern University

Assaf Naor, professor of mathematics: **2018 Frederic Esser Nemmers Prize in Mathematics**

PEN America Center

Edmund White, professor of creative writing in the Lewis Center for the Arts, emeritus: **2018 PEN/Saul Bellow Award for Achievement in American Fiction**

Phi Beta Kappa Society

Nancy Weiss Malkiel, professor of history, emeritus: **2018 Sidney Hook Memorial Award**

Pulitzer Prize Board

Matthew Desmond, Maurice P. During Professor of Sociology: **2017 Pulitzer Prize in General Nonfiction**

Research & Development Council of New Jersey

Craig Arnold, professor of mechanical and aerospace engineering: **2017 Edison Patent Award, Technology Transfer**

Manfred Bitter, principal research physicist, Princeton Plasma Physics Laboratory: **2017 Edison Patent Award, Imaging Systems**

Philip Efthimion, head, plasma science and technology, Princeton Plasma Physics Laboratory; lecturer in astrophysical sciences: **2017 Edison Patent Award, Imaging Systems**

Kenneth Hill, principal research physicist, Princeton Plasma Physics Laboratory: **2017 Edison Patent Award, Imaging Systems**

Simons Foundation

Steven Gubser, professor of physics: **2017 Simons Investigator Award, Physics**

Eve Ostriker, professor of astrophysical sciences: **2017 Simons Investigator Award, Astrophysics**

Ran Raz, professor of computer science: **2018 Simons Investigator Award, Theoretical Computer Science**

Igor Rodnianski, professor of mathematics: **2017 Simons Investigator Award, Mathematics**

Amit Singer, professor of mathematics and the Program in Applied and Computational Mathematics: **2017 Simons Investigator Award, Math+X**

Allan Sly, Henry Burchard Fine Professor of Mathematics: **2017 Simons Investigator Award, Mathematics**

Society for Developmental Biology

Eric Wieschaus, Squibb Professor in Molecular Biology, professor of molecular biology and the Lewis-Sigler Institute for Integrative Genomics: **2018 Lifetime Achievement Award**

Society for Ethnomusicology

Gavin Steingo, assistant professor of music: **2017 Alan Merriam Prize**

Society of Labor Economists

Henry Farber, Hughes-Rogers Professor of Economics: **2018 Jacob Mincer Award**

U.S. Department of Energy's Office of Science

Nathaniel Fisch, professor of astrophysical sciences: **2017 One of 40 Research Milestones over the Past 40 Years**

University of California–Berkeley Center for Buddhist Studies

Jacqueline Stone, professor of religion: **2017 Toshihide Numata Book Award**

University of Pittsburgh School of Medicine

Bonnie Bassler, Squibb Professor in Molecular Biology; chair, Department of Molecular Biology: **2018 Dickson Prize in Medicine**

Gillian Knapp receives presidential award for STEM mentorship

PHOTO BY DENISE APPLEWHITE

Gillian Knapp

Gillian Knapp, an emeritus professor of astrophysical sciences and senior scholar, has received the National Science Foundation's Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring.

Knapp taught at Princeton for 34 years and was one of the first women to join the science faculty. In 2005, she founded the Princeton Prison Teaching Initiative (PTI), a leader in providing college-accredited classes to incarcerated individuals. The Presidential Award recognizes Knapp's work in founding PTI, as well as her role in developing and expanding mentorship opportunities for undergraduate and graduate students in the Department of Astrophysical Sciences, where she helped foster a diverse and inclusive student and faculty community. **–By Emily Aronson**

International Prizes and Distinctions

BBVA Foundation

B. Rosemary Grant, senior research biologist, emeritus; senior biologist, ecology and evolutionary biology: **2018 Frontiers of Knowledge Award**

Peter Grant, Class of 1877 Professor of Zoology, Emeritus; professor of ecology and evolutionary biology, emeritus: **2018 Frontiers of Knowledge Award**

Chinese Academy of Sciences

H. Vincent Poor, Michael Henry Strater University Professor of Electrical Engineering: **2017 Foreign Member**

Hungarian Academy of Sciences

Gáspár Bakos, professor of astrophysical sciences: **2017 Dénes Gábor Award**

International Association of Mathematical Physics

Michael Aizenman, professor of physics and mathematics: **2018 Henri Poincaré Prize**

King's College, University of Cambridge

Michael Cook, Class of 1943 University Professor of Near Eastern Studies: **2018 Honorary Fellow**

National Economics Foundation, China

Gregory Chow, Class of 1913 Professor of Political Economy, Emeritus; professor of economics, emeritus: **2017 China Economics Prize**

Queen Elizabeth II

Steven Cowley, director, Princeton Plasma Physics Laboratory; professor of astrophysical sciences: **2018 Knighthood**

Royal College of Music

Michael Pratt, conductor, Princeton University Orchestra; director, Program in Musical Performance: **2018 Honorary Member**

Royal Spanish Mathematical Society

Javier Gómez-Serrano, assistant professor of mathematics: **2017 Vicent Caselles Mathematical Research Award**

Royal Swedish Academy of Sciences and the Crafoord Foundation

Syukuro Manabe, senior meteorologist, atmospheric and oceanic sciences: **2018 Crafoord Prize in Geosciences**

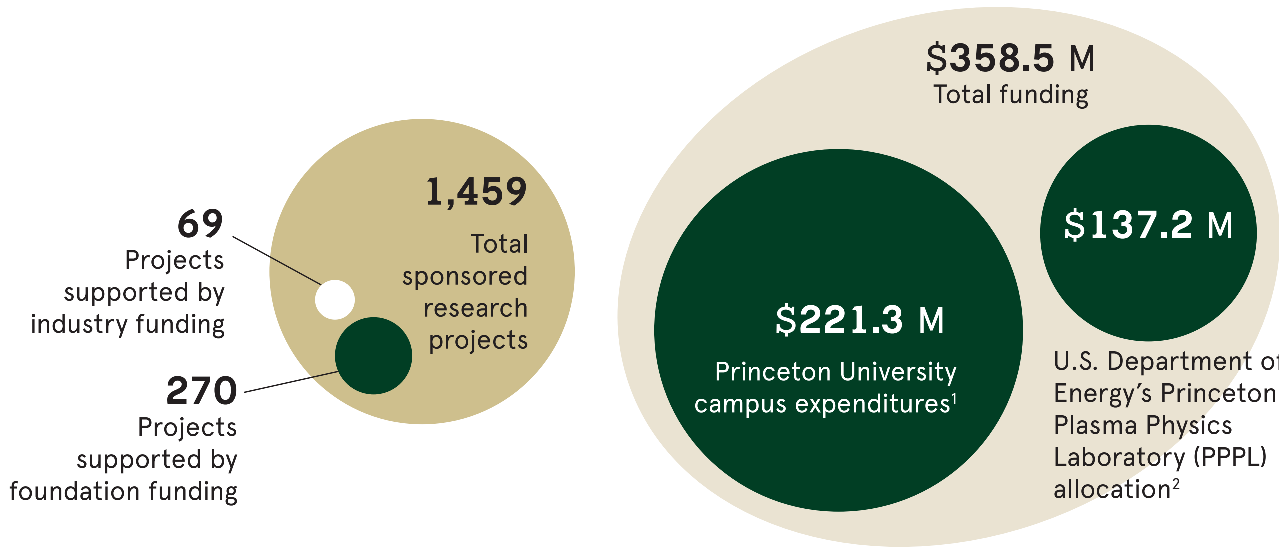
Wissenschaftskolleg zu Berlin

Beatriz Colomina, professor of architecture: **2018 Fellow**

Innovation Indicators

Fiscal year 2018

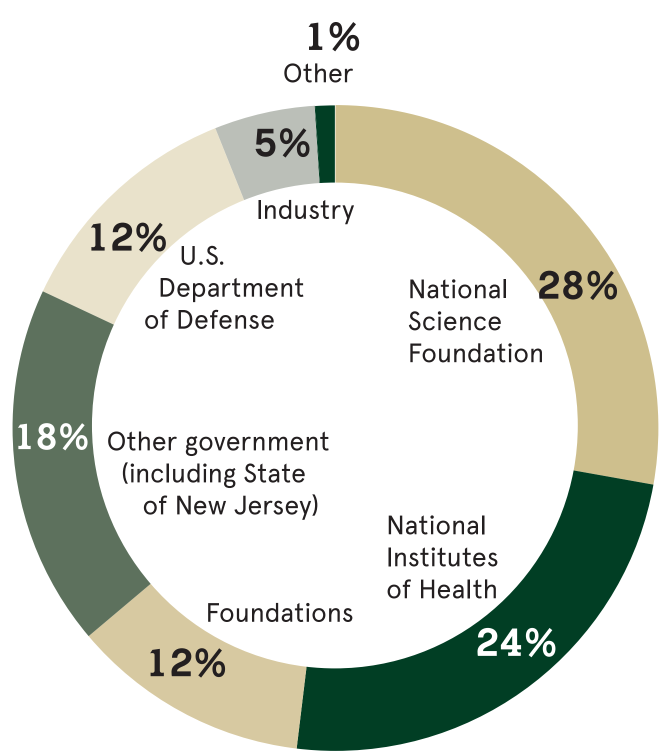
Sponsored Research Projects



[1]Expenditures for fiscal year July 1–June 30.

[2]Amount allocated for fiscal year Oct. 1–Sept. 30.
Funding does not include pass-through procurements related to ITER, an international fusion experiment.

Funding Sources for Sponsored Research Activities (Campus)



Technology Licensing Activities

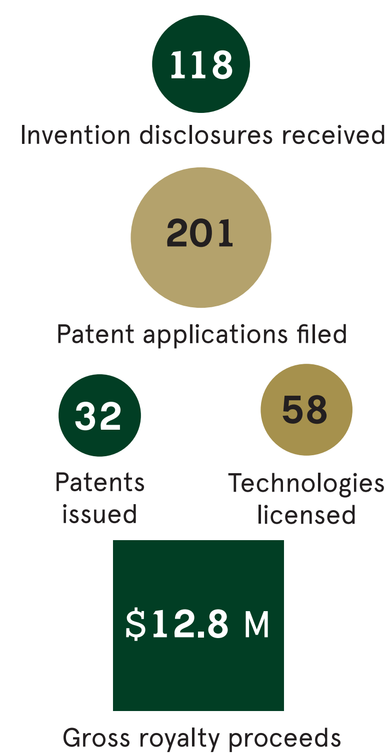


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PHOTO BY DAVID KELLY CROW

Jennifer Rexford is the chair of Princeton's Department of Computer Science and the Gordon Y.S. Wu Professor in Engineering. "Princeton computer science faculty members are pushing the envelope on scientific discovery by combining a deep understanding of the underlying science with innovation in algorithms and computer systems. Better yet, this is only the beginning, with the opportunity to transform scholarship in a wide range of disciplines across campus."

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A major new exhibition, *Nature's Nation: American Art and Environment*, explores how American artists of different traditions and backgrounds have reflected and shaped environmental understanding and our changing relationship with the natural world. See page 26.

Below: Thomas Moran, American, 1837–1926, *Lower Falls, Yellowstone Park (Grand Canyon of the Yellowstone)*, 1893. Oil on canvas. Gilcrease Museum, Tulsa, Oklahoma.

After its premiere at the Princeton University Art Museum (Oct. 13, 2018–Jan. 6, 2019), the exhibition travels to the Peabody Essex Museum in Salem, Massachusetts (Feb. 2–May 5, 2019), and to the Crystal Bridges Museum of American Art in Bentonville, Arkansas (May 25–Sept. 9, 2019).