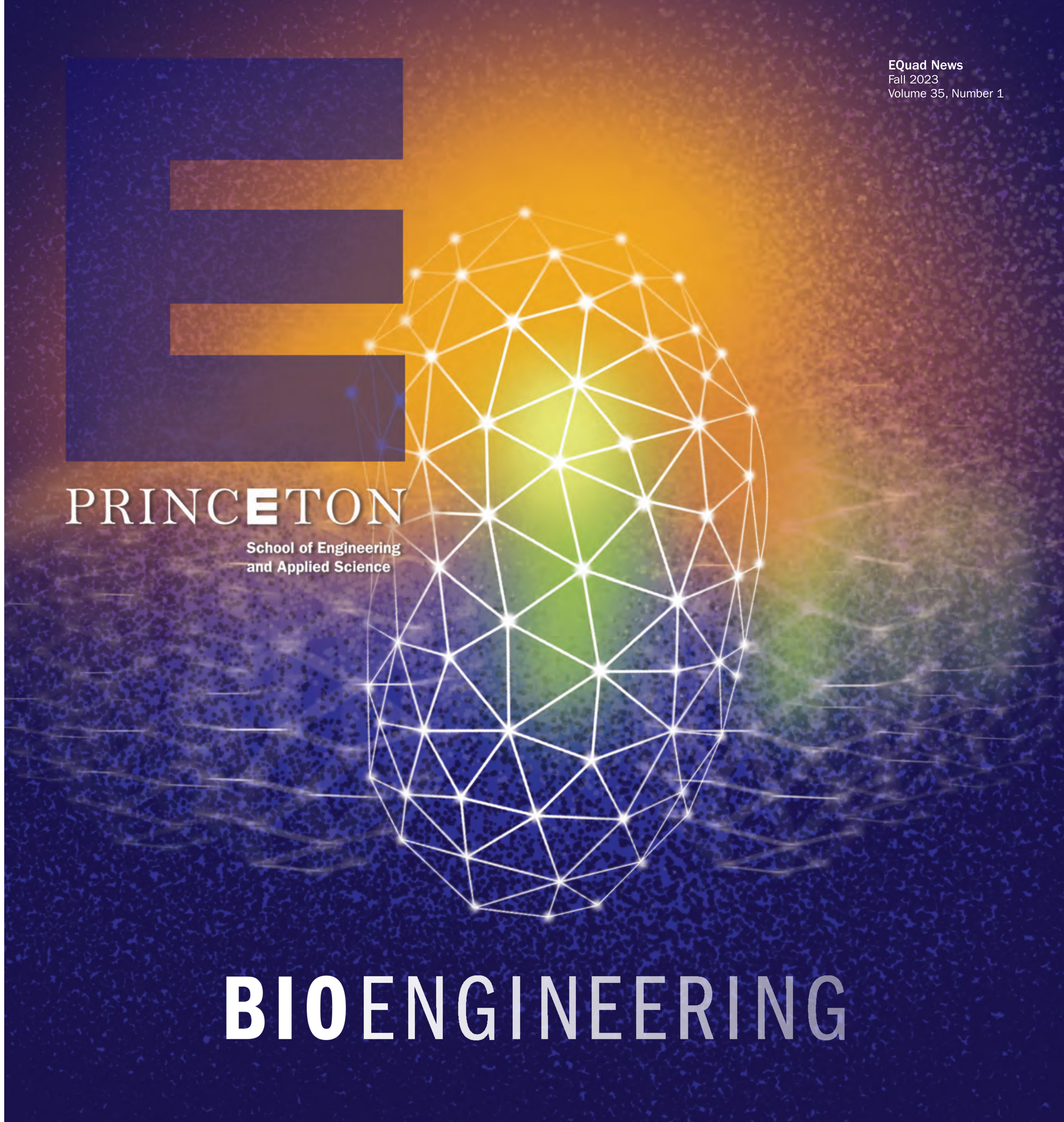
PRINCETON UNIVERSITY

School of Engineering and Applied Science
Princeton, NJ 08544
engineering.princeton.edu

eqn@princeton.edu



DEAN'S NOTE

Unlocking mysteries, enabling impact

In their individual careers and collaborative work, the faculty associated with our new Omenn-Darling Bioengineering Institute have made pathbreaking discoveries, unlocking deep mysteries about the mechanisms of life and opening vistas toward new medicines, diagnostics, sustainable energy, and other life-improving technologies.

As Princeton University makes bold investments in engineering, the Omenn-Darling Institute exemplifies how we are accelerating the positive impacts of our work for society. Through the generosity of alumni Gil Omenn '61 and Martha Darling *70, the new institute brings together expertise across engineering, computer science, and the natural sciences. A new building for bioengineering, due to open in 2025, will bring under one roof a community united in a desire to develop new knowledge and technologies at the intersection of biology and engineering that can significantly help humanity.

Beyond bioengineering, this combination of curiosity and urgency underlies all our areas of growth, such as robotics, quantum engineering, artificial intelligence, blockchain, next-generation wireless, and energy and the environment. In these and other areas we are adding faculty and graduate students and building an entirely new neighborhood to foster the community and collaboration needed for discovery and impact.

I hope that you will continue to follow our progress and share your own stories of curiosity, collaboration, and impact.

Andrea Goldsmith
Dean
Arthur LeGrand Doty
Professor of Electrical
and Computer Engineering

EQuad News
Fall 2023
Volume 35, Number 1

Dean
Andrea Goldsmith

Vice Dean
Antoine Kahn *78

Associate Dean, Undergraduate Affairs
Peter Bogucki

Associate Dean, Development
Jane Maggard

Associate Dean, Diversity and Inclusion
Julie Yun

Director of Engineering Communications
Steven Schultz

Senior Editor
John Sullivan

Digital Media Editor
Aaron Nathans

Writer
Molly Sharlach

Senior Engineering Communications Strategist
Scott Lyon

Communications Specialists
Julia Schwarz
Wright Señeres

Development and Communications Coordinator
Christine Fairsmith

Contributors
Adam Hadhazy
Colton Poore

Graphic Designer
Matilda Luk

Web Designer
Neil Adelantar

EQuad News is published twice a year by the Office of Engineering Communications in collaboration with the Princeton University Office of Communications.

Note on alumni class years
Following Princeton University convention, undergraduate alumni are indicated by an apostrophe and class year; graduate alumni, whether master's or doctoral, are indicated with a star and class year.

EQuad News
C-222, EQuad,
Princeton University
Princeton, NJ 08544
T 609 258 4597
F 609 258 6744
eqn@princeton.edu

https://engineering.princeton.edu/news/equad-magazine

Olga Troyanskaya, top right, leading a seminar for undergraduates on precision health research. Photo by Tori Repp/Fotobuddy

USING THE TOOLS OF COMPUTER SCIENCE TO IMPROVE HEALTH CARE

Last spring, a team of Princeton students gathered weekly in a small seminar room to study medicine. But no stethoscopes or scalpels were involved. The students were using computers.

"Medicine is becoming more and more a data-driven enterprise," said Olga Troyanskaya, the seminar instructor. Troyanskaya, a professor of computer science and the Lewis-Sigler Institute for Integrative Genomics, is the director of a new University initiative, Princeton Precision Health. Integrating computer science, biology, social science, policy, psychology, ethics, and medicine, the initiative uses large, complex data sets to make health care policy and delivery more precise, effective, and unbiased.

The project focuses on three areas: kidney disease and diabetes, the immune system and inflammation, and neurodevelopment and mental health. In each, Troyanskaya said, "there is enormous unmet need to develop precision medicine approaches and correct existing biases." In the case of chronic kidney disease, Princeton Precision Health is collaborating with large initiatives that generate data at the genetic, molecular, socioeconomic, and clinical levels. There are also well-documented racial disparities in the incidence of chronic kidney disease.

The initiative's goal is to take a comprehensive, data-driven approach to this type of health care challenge. Currently, social scientists rarely include comprehensive genetic information in their work, and computational biologists rarely use social science data. Instead of working in silos, the initiative brings together experts to collaborate on interdisciplinary data sets created with cutting-edge tools. Ethical frameworks and behavioral modeling are essential for achieving effective and unbiased clinical outcomes and health policies, Troyanskaya said.

Troyanskaya's inaugural undergraduate course in computational methods in precision health filled quickly and attracted a waiting list. Students researched topics including microscopic anatomy, access to abortion care, and racial bias in cancer treatment.

Aria Nagai, now a senior, said that what drew her to this topic was its focus on using computer science tools to address real-world problems. "I'm not super interested in the theory behind algorithms," she said. "I'm more interested in learning how to use algorithms or machine learning to help others."

– by Julia Schwarz

A NEW ROUTE TO A QUANTUM INTERNET

Researchers have a new way to connect quantum devices over long distances, a necessary step toward allowing the technology to play a role in future communications systems.

While today's classical data signals can get amplified across a city or an ocean, quantum signals cannot. They must be repeated in intervals — that is, stopped, copied, and passed on by specialized machines called quantum repeaters. Many experts believe these quantum repeaters will play a key role in future communication networks, allowing enhanced security and enabling connections between remote quantum computers.

A Princeton study, published in the journal Nature, details the basis for a new approach to building quantum repeaters. It sends telecom-ready light emitted from a single ion implanted in a crystal. The effort was many years in the making, according to Jeff Thompson, the study's principal author and an associate professor of electrical and computer engineering. The work combined advances in photonic design and materials science.

Other leading quantum repeater designs emit light in the visible spectrum, which degrades quickly over optical fiber and must be converted before traveling long distances. The new device is based on a single rare earth ion implanted in a host crystal. And because this ion emits light at an ideal infrared wavelength, it requires no such signal conversion, which can lead to simpler and more robust networks.

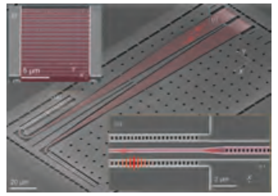
The device has two parts: a calcium tungstate crystal doped with just a handful of erbium ions, and a nanoscopic piece of silicon etched into a J-shaped channel. Pulsed with a special laser, the ion emits light up through the crystal. But the silicon piece, a wisp of a semiconductor stuck onto the top of the crystal, catches and guides individual photons out into the fiber optic cable.

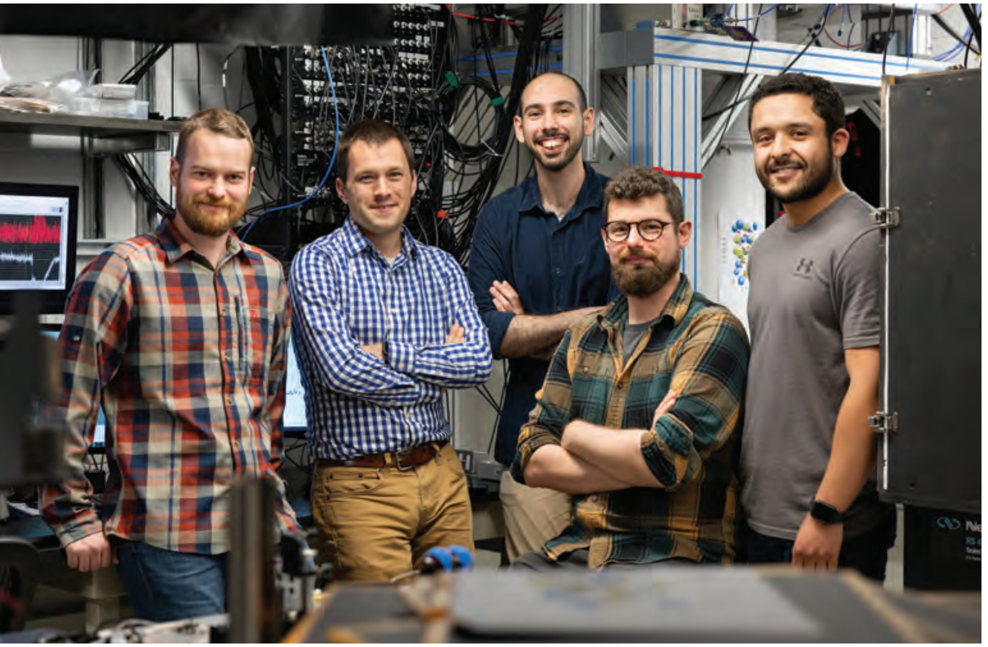
Thompson's team worked with Nathalie de Leon, associate professor of electrical and computer engineering, and Robert Cava, a leading solid-state materials scientist and Princeton's Russell Wellman Moore Professor of Chemistry, to explore new materials that could host single erbium ions.

They winnowed the list of candidate materials from hundreds of thousands down to a few hundred, then a couple dozen, then three. Each of the three finalists took half a year to test. The first material turned out to be not quite clear enough. The second caused the erbium to have poor quantum properties. But the third, the calcium tungstate, was just right.

While this work crosses an important threshold, additional research is required to improve the storage time of quantum states in the spin of the erbium ion. The team is currently exploring how to make more highly refined calcium tungstate, with fewer impurities that disturb the quantum spin states. – **by Scott Lyon**

Thompson's team designed a nanoscopic silicon waveguide to capture the photons emitted by erbium ions and send them as high-fidelity signals over the fiber optic cable. Image courtesy of the researchers





Princeton researchers led by associate professor Jeff Thompson (second from left) have developed a new approach to linking quantum computers over long distances. The new system transmits low-loss signals over optical fiber using light in the telecom band, a longstanding goal in the march toward robust quantum communication networks. Photo by Sameer A. Khan/Fotobuddy

THE WORLD HAS A FOOD-WASTE PROBLEM. CAN THIS WIRELESS TECH HELP FIX IT?

One bad apple may not spoil the bunch, but when it comes to distributing food, a lot of good goes out with the bad.

Researchers from Princeton University and Microsoft Research have developed a fast and accurate way to determine fruit quality using high-frequency wireless technology. The tool gives suppliers a way to sort fruit based on fine-grained ripeness measurements. It promises to help cut food waste by optimizing distribution.

Current methods to determine ripeness are either unreliable, overly broad, too time-consuming, or too expensive to implement at large scales, according to a study the researchers presented at the 2023 ACM MobiCom conference on networking and mobile computing in October.

"There is no systematic way of determining the ripeness status of fruits and vegetables," said Yasaman Ghasempour, assistant professor of electrical and computer engineering at Princeton and one of the study's principal investigators. "It is mostly random visual inspection."

But this kind of visual inspection leads to poor estimates much of the time, she said. Rather than rely on how the peel looks or how it feels to the touch, advanced wireless signals can effectively peek under the surface of a piece of fruit and reveal richer information about its quality.

The team, led by Ghasempour and Ranveer Chandra of Microsoft, developed a system for determining ripeness using wireless signals in the sub-terahertz band that can scan fruit on a conveyor belt. The sub-terahertz signals — between microwave and infrared — interact with the fruit in ways that can be measured in fine detail, leading to readouts of sugar and dry matter content beneath the surface of the fruit's skin.

By modeling the physics of these interactions and procuring a lot of data, the researchers were able to use that signature to reveal the fruit's ripeness status.

Princeton and Microsoft researchers have found a way to bring next-generation wireless technologies to bear on the massive problem of food waste, with a system that can effectively peek under the surface and determine the quality of a piece of fruit. The advance could help vendors optimize distribution and slash waste. The researchers scanned fruit in regular intervals over several weeks to understand their ripeness signatures. The experiment looked at persimmons, apples, and avocados, but the system can be generalized to many kinds of food. Photo by Sameer A. Khan/Fotobuddy

"It was really challenging to develop a model for this," Ghasempour said. She said fruits' many structural layers — seeds, pulp, skin — added complexity to the problem.

Smooth skinned fruits are easiest to measure. Uneven skin, like an avocado's, reflects a weaker signal and produces unwanted effects. But the researchers found ways to get around the bumpiness problem and say that with enough data the method can be applied to most fruits.

They believe this tool can be extended to other kinds of foods by using different kinds of physiological markers. Those extended use cases could have big implications for food safety monitoring and consumer choice.

– **by Scott Lyon**

USING DRONES AND LASERS, RESEARCHERS PINPOINT GREENHOUSE GAS LEAKS

As evidence mounts that gas drilling and sewer systems leak far more greenhouse gases than previously believed, a team of Princeton researchers has developed a method to pinpoint leaks both big and small for speedy repair.

Their laser-based sensing approach can accurately detect and quantify both large greenhouse gas leaks and leaks up to 25 times smaller than those typically detected at natural gas facilities using other methods, localizing the emissions source to within a meter. Because it takes advantage of the remote-sensing capabilities of lasers combined with the agility of drones, the new technology can also be used to quickly spot otherwise unseen leaks in hard-to-access areas, an innovation the researchers said unlocks game-changing potential for atmospheric sensing.

"Current approaches for detecting leaks often rely on handheld infrared cameras that are labor-intensive to operate and insensitive to small leaks, or they use methods that require setting up extensive measurement infrastructure ahead of time," said Gerard Wysocki, associate professor of electrical and computer engineering and associated faculty at the Andlinger Center for Energy and the Environment. "But with a drone, you are completely free in how you are able to set up your sensing area."

The researchers' approach consists of a small drone outfitted with only a retroreflector, a type of mirror that reflects incoming light directly back to the source, and a base station of gas sensing equipment with the capability to track the drone's movement during flight. Bouncing a laser beam off the drone as it flies to set points around a suspected leak allows an operator to pinpoint the source of the leak and measure its intensity.

"That's really the holy grail of leak detection," said Mark Zondlo, study coauthor, professor of civil and environmental engineering, and associated faculty at the Andlinger Center for Energy and the Environment.

The sensing method could also enable simultaneous measurements of multiple gases, a feat that is exceedingly difficult with other drone-based approaches due to size, weight, and power considerations. Michael Soskind, the first author of the study and a graduate student in electrical and computer engineering, said adding the ability to measure other gases like carbon dioxide and ammonia alongside methane would be as simple as adding other lasers of different wavelengths to the base system. "All you'd need to do is add a secondary laser to the system," he explained. "The rest of the system is already built out to do the work." **– by Colton Poore**

Michael Soskind, first author and graduate student in electrical and computer engineering, stands with the drone. Photo by Bumper DeJesus

REVOLUTIONIZING LITHIUM PRODUCTION ON A STRING

A vital component of the batteries at the heart of electric vehicles and grid energy storage, lithium is key to a clean energy future. But producing the silvery-white metal comes with significant environmental costs. Among them is the vast amount of land and time needed to extract lithium from briny water, with large operations running into the dozens of square miles and often requiring over a year to begin production.

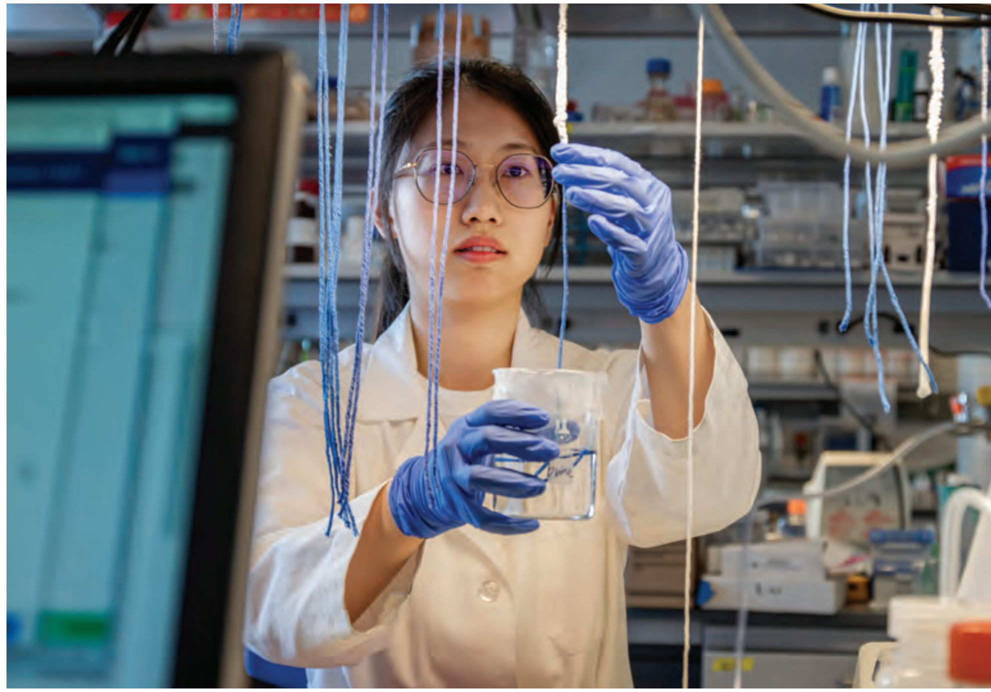
Now, researchers at Princeton have developed an extraction technique that slashes the amount of land and time needed for lithium production. The researchers say their system can improve production at existing lithium facilities and unlock sources previously seen as too small or diluted to be worthwhile.

The core of the technique is a set of porous fibers twisted into strings, which the researchers engineered to have a water-loving core and a water-repelling surface. When the ends are dipped in a salt-water solution, the water travels up the strings through capillary action — the same process trees use to draw water from roots to leaves. The water quickly evaporates from each string's surface, leaving behind salt ions such as sodium and lithium. As water continues to evaporate, the salts become increasingly concentrated and eventually form sodium chloride and lithium chloride crystals on the strings, allowing for easy harvesting.

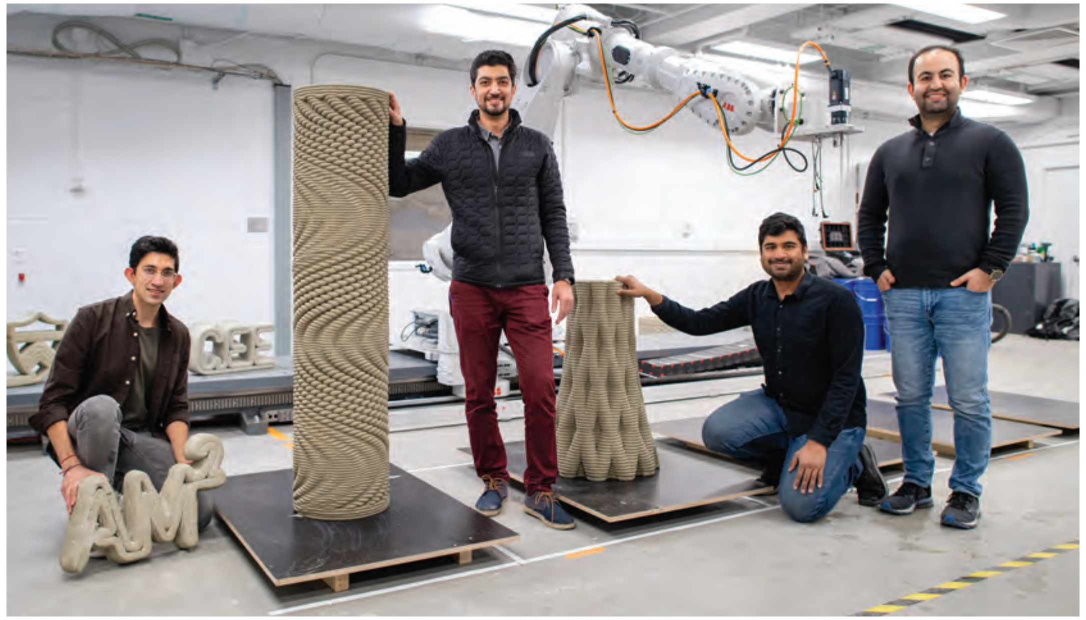
In addition to concentrating the salts, the technique causes lithium and sodium to crystallize at distinct locations along the string due to their different physical properties. Sodium, with low solubility, crystallizes on the lower part of the string, while the highly soluble lithium salts crystallize near the top. The natural separation allowed the team to collect lithium and sodium individually, a feat that typically requires the use of additional chemicals.

"We aimed to leverage the fundamental processes of evaporation and capillary action to concentrate, separate, and harvest lithium," said Z. Jason Ren, professor of civil and environmental engineering and the Andlinger Center for Energy and the Environment at Princeton and the leader of the research team. "We do not need to apply additional chemicals, as is the case with many other extraction technologies, and the process saves a lot of water compared to traditional evaporation approaches."

Limited supply of lithium is one obstacle to the transition to a low-carbon society, Ren added. "Our approach is cheap, easy to operate, and requires very little energy. It's an environmentally friendly solution to a critical energy challenge."
– by Colton Poore



Above: Meiqi Yang, a graduate student in civil and environmental engineering, operates a new string-based approach for lithium extraction. Photo by Bumper DeJesus
Left: Yang is a lead author of a study featured on the cover of the September 2023 issue of Nature Water.



Princeton researchers are working to improve the use of additive manufacturing for concrete and other cement-based materials. The research team, from left to right, Arjun Prihar, Reza Moini, Shashank Gupta, and Hadi Esmaeeli. Photo by Sameer A. Khan/ Fotobuddy

LASERS PAVE THE WAY TO BETTER USE OF CEMENT

Engineers at Princeton are deploying lasers to precisely evaluate a major drawback of 3D-printed cement — the material's tendency to fracture. The researchers hope that progress in this area could lead to a wider use of additive manufacturing in cement-based structures. The long-term goal is to develop better materials using additive techniques that lead to innovative designs and functions.

Cement is the major ingredient in the concrete that makes up much of modern construction — including buildings, roads, runways, bridges, and dams. In recent years, as 3D printing has demonstrated advantages in efficiency and versatility, there has been a growing interest in applying the technology to construction.

But compared to conventionally cast concrete, 3D-printed alternatives can be subject to cracking, particularly in areas between different layers of concrete. Researchers attribute this to non-uniform microstructures introduced by the layering process used in 3D printing. Princeton researchers have used a new test to better understand this cracking at a microscopic level. Their findings suggest that by properly characterizing the fracturing properties, 3D-printed concrete could be just as strong or even stronger than cast concrete.

In a study in the journal Cement and Concrete Composites, the researchers demonstrated a new testing method that uses lasers to cut precisely located grooves in 3D-printed cements. By controlling the power and speed of the laser, the researchers can control critical features such as the grooves' depth and shape. This control allows for far more accurate testing than conventional methods.

"We can now gain a more thorough understanding of the fracture properties of 3D-printed cement-based materials under various modes of failure, which is important for eventually scaling up this technology," said Reza Moini, an assistant professor in the Department of Civil and Environmental Engineering and senior author of the study. "There are new opportunities to make stronger and tougher materials by leveraging the design of materials architecture and fabrication freedom that comes with additive technologies."
– by Adam Hadhazy

BURSTING BUBBLES MOVE MICROPLASTICS FROM THE OCEAN TO THE ATMOSPHERE

Using high-speed photography, researchers at Princeton and Cornell University demonstrated that the ocean can transport microplastics into the atmosphere, adding to evidence that the sea may not be the final resting place for plastic pollution.

In a paper published in PNAS Nexus, the researchers showed that bursting bubbles formed from breaking waves can launch into the atmosphere tiny bits of plastic from items such as broken-down plastic bottles, synthetic clothing fibers, and cosmetic products. Combining their observations with global estimates of microplastic concentrations, the researchers projected that the ocean might be emitting around 100,000 metric tons of microplastics each year.

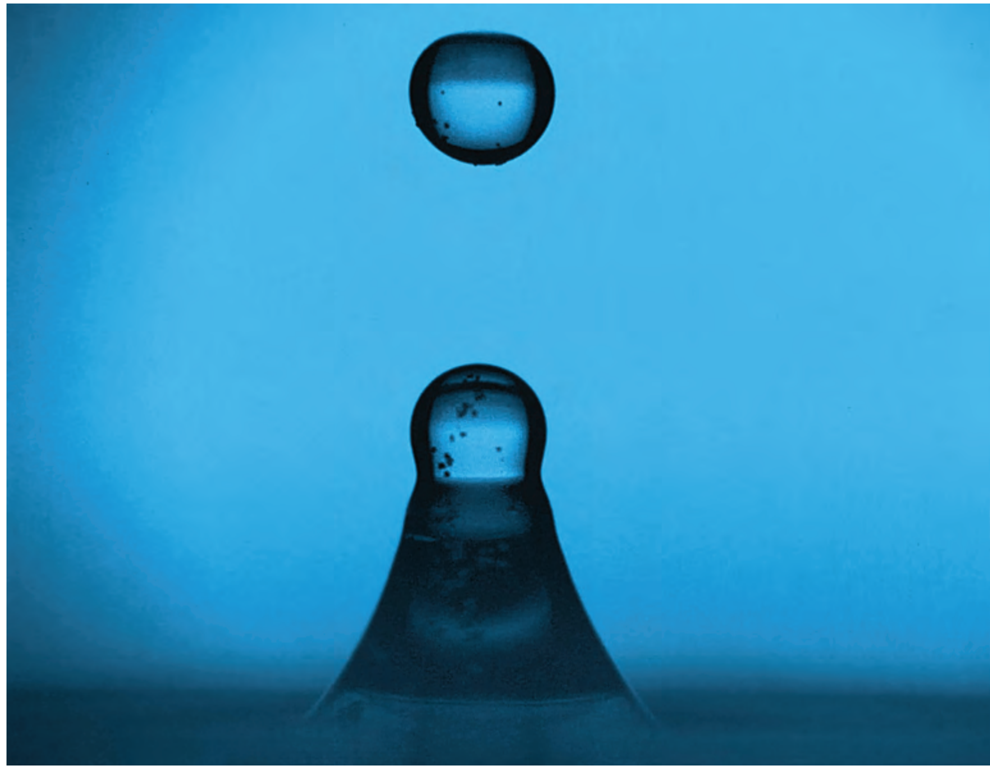
"These bursting bubbles have been shown to transport salt crystals and bacteria into the atmosphere, enough to influence cloud formation and global climate dynamics," said Luc Deike, primary researcher and associate professor of mechanical and aerospace engineering and the High Meadows Environmental Institute. "The same process is also capable of carrying microplastic particles out of the ocean and into the atmosphere."

Once microplastics leave the ocean's surface, the researchers said that surface winds can transport them high into the atmosphere and then across long distances. Deike said recent evidence of microplastics in areas as remote as the Arctic and Antarctica helped motivate the research.

"Anything that you dump in the ocean is probably going to come back to you in one form or another," Deike said. "While the process we described is not likely to dominate global budgets for microplastics, if it's one of the ways that microplastics end up in Antarctica or on remote islands in the middle of the ocean, then the number becomes even more significant."

The researchers said their work provides a reliable estimate of the size and number of microplastics that can be transported out of the ocean given a few known parameters, such as the size of the bubble and the concentration of microplastics at the ocean's surface. However, they argued there is still considerable uncertainty about how microplastics are distributed in time and space across the ocean. They concluded that more work is needed to sample microplastics at the sea's surface to refine their estimate of the ocean's contribution to the global microplastics budget.

"At this point, microplastics have been found in almost every corner of the planet," Deike said. "Ultimately, it really becomes a question of how much microplastic pollution we are willing to accept." **– by Colton Poore**



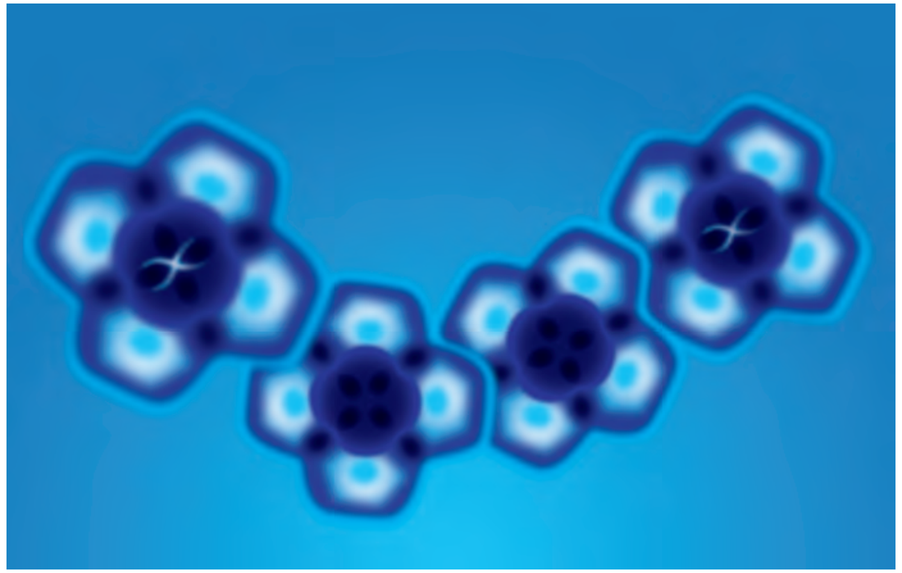
Researchers showed that bursting bubbles formed from breaking waves can launch tiny bits of plastic into the atmosphere. They projected that the ocean might be emitting around 100,000 metric tons of microplastics each year. Video still courtesy of the researchers

LIKE FACIAL RECOGNITION FOR ATOMS, IMAGE DISTINGUISHES ELEMENTS BY ELECTRON ORBITALS

Orchestrating an array of advanced microscopes, researchers at Princeton and the University of Texas at Austin have created images of molecules with such clarity that it is possible to distinguish iron from cobalt by the orbital shapes of buzzing electrons.

Chemists have long used abstract shapes to describe electron orbitals, which are crucial to how atoms and molecules behave. However, this groundbreaking study marks the first direct observation of these orbital shapes, rather than inferring them based on chemical reactions.

"People have predicted certain orbital structures, but they have never seen them," said Nan Yao, a lead researcher and the director of the Imaging and Analysis Center at the Princeton Materials Institute. Yao, a professor of the practice at Princeton, said the research team was surprised when they first looked at the images and were able to distinguish one element from another by the orbital shapes alone.



Researchers were able to use the image to distinguish between chemically similar elements cobalt and iron. Photo illustration by Matilda Luk

No longer are electron orbitals the simple spheres and dumbbells of chemistry textbooks. Instead, these atoms revealed distinct features which allowed the researchers to tell cobalt from iron in the same way a birdwatcher could tell a blue jay from a bluebird. In the image, the iron atom has a squarish shape, while cobalt is brighter with more distinct lobes in its electron orbitals.

The researchers, reporting in the journal Nature Communications, found it was possible to distinguish electron orbital structures of atoms within a molecule using an atomic force microscope. The microscope operates by running an incredibly sharp probe, in this case a single carbon monoxide molecule, over a target molecule's surface. The probe responds to quantum forces from the target, sending data to the microscope's computer and displaying a direct image. Researchers then used supercomputers at the University of Texas at Austin to perform the calculations that allowed them to create simulated images that show the same orbital patterns of electrons within the molecules.

"It is so amazing to see this for the first time, actually to see it," said Craig Arnold, one of the project's researchers.

Arnold, the Susan Dod Brown Professor of Mechanical and Aerospace Engineering and vice dean for innovation at Princeton, said that understanding the properties of electron orbitals is a foundation of physics and chemistry. He said that science has unlocked many properties through measurement and experiments, but observing molecules directly provides a new way of comprehending their behavior. This knowledge can be used by scientists to gain deeper understanding, improve the design of new materials, and shape chemical reactions. **– by John Sullivan**

Princeton researchers have developed an open-source software system that generates an infinite number of photorealistic scenes of the natural world, an advance that could improve the training of autonomous cars and other robots. Image courtesy the researchers

ENGINEERS LOOK TO AN OLD SOURCE TO EMPOWER THE FUTURE OF COMPUTER VISION

Artificial intelligence seems perfect for creating massive sets of images needed to train autonomous cars and other machines to see their environment, but current generative AI systems have shortcomings that can limit their use. Now, engineers at Princeton have developed a software system to overcome those limits and quickly create image sets to prepare machines for nearly any visual setting.

The new system, called Infinigen, relies on mathematics to create natural-looking objects and environments in three dimensions. Infinigen is a procedural generator, which in computer science denotes a program that creates content based on automated, human-designed algorithms rather than labor-intensive manual data entry or the neural networks that power modern AI. In this way, the new program generates myriad 3D objects using only randomized mathematical rules.

Infinigen is "a dynamic program for building unlimited, diverse, and realistic natural scenes," said Jia Deng *12, an associate professor of computer science at Princeton and senior author of a study that details the software system.

Infinigen's mathematical approach allows it to create labeled visual data, which is needed to train computer vision systems, including those deployed on home robots and autonomous cars. Because Infinigen generates every image programmatically — it creates a 3D world first, populates it with objects, and places a camera to take a picture — Infinigen can automatically provide detailed labels about each image, including the category and location of each object.

The images with automatic labels can then be used to train a robot to recognize and locate objects given only an image as input. Such labeled visual data would not be possible with existing AI image generators, according to Deng, because those programs generate images using a deep neural network that does not allow the extraction of labels.

In addition, Infinigen's users have fine-grained control of the system's settings, such as the precise lighting and viewing angle, and can fine-tune the system to make images more useful as training data.

Besides generating virtual worlds populated by digital objects with natural shapes, sizes, textures, and colors, Infinigen's capabilities extend to synthetic representations of natural phenomena including fire, clouds, rain, and snow.

"We expect that Infinigen will prove to be a useful resource not just for creating training data for computer vision, but also for augmented and virtual reality, game development, filmmaking, 3D printing, and content generation in general," Deng said.
– by Adam Hadhazy

ENGINEERS CLEAN UP WITH TIDYBOT

Engineers at Princeton have built a robot to help with that most essential household task: tidying up.

Robots excel at simple tasks like moving a pile of objects from the floor into a bin. But real-world household cleanup requires more complicated skills. Robots must distinguish among different objects, place them at designated locations, and avoid breaking them.

"You might throw a T-shirt into the laundry pile, but there are some things you really shouldn't throw, like dishes into a sink," said Szymon Rusinkiewicz, the David M. Siegel '83 Professor of Computer Science and one of three senior authors on a research paper about the new robot, called TidyBot.

Tidying up requires a robot with three distinct skills: physical dexterity, visual recognition, and some amount of common sense. The researchers achieved this with TidyBot by combining a mobile robotic arm with a vision model and a large language model.

TidyBot can carefully place dishes in the sink, throw T-shirts on the laundry pile, or put empty cans in the recycling bin. Video still courtesy of the researchers

TidyBot's arm is attached to a square base that scoots around on four wheels, and its hand is a pincer that can pick up objects and open drawers. This gives it the physical ability to carefully place dishes in the sink or throw T-shirts on the laundry pile. A camera paired with a vision model lets it distinguish between types of objects, like a pair of pants and a banana peel. Finally, by programming it with a large language model, TidyBot can learn to gently place a wine glass on a shelf while casually tossing a stuffed animal into a toy bin.

In testing, TidyBot correctly determined the category of objects and where to put them — as in, place toys in the box and put clothes on the floor — for 85% of objects. "We were quite surprised by the results, because the language and vision models we used are very general and not specifically trained for this type of task," said Jimmy Wu, the paper's first author and a graduate student in computer science.

TidyBot's success is especially noteworthy, Rusinkiewicz added, because it can infer and generalize from so few instructions. "This is in contrast to general machine learning," he said, "where you need lots of examples for everything." Creating an exhaustive list of instructions for household cleanup would require significant effort and constant maintenance, limiting the robot's real-world usefulness.

While very good at distinguishing between categories of things, like toys and clothes, TidyBot is not as good yet at sorting objects based on attributes, like metal versus plastic. It also has trouble with subcategories, like shirts versus other clothes. Fine-tuning this is one possible area of future research, said Wu.
– by Julia Schwarz

BIOENGINEERING

At Princeton's new institute, the quest for better lives starts with curiosity.

Like living organisms, the new Omenn-Darling Bioengineering Institute is built to thrive as a community, mixing disciplines to create a new synthesis of ideas and techniques that improve the health of people and the planet.

The new institute, supported with a transformational gift to Princeton's Venture Forward campaign by alumni Gilbert Omenn '61 and Martha Darling *70, is promoting new directions in research, education, and innovation at the intersection of engineering and the life sciences, while growing interdisciplinary bioengineering postdoctoral, graduate, and undergraduate programs.

"This institute allows us to coalesce and amplify on-going work into a transformative new whole that will accelerate Princeton's leadership in bioengineering for decades to come," said Andrea Goldsmith, dean of the School of Engineering and Applied Science. "The institute brings together the most innovative faculty and students in the field and provides them with the foundation to realize bioengineering's enormous potential for positive impact on health, medicine, and quality of life." ▶

Building on the previous Princeton Bioengineering Initiative, the Omenn-Darling Bioengineering Institute (ODBI) is growing from a base of 35 core and affiliated faculty from across the University, a new Ph.D. program, and strong ties to the region's life sciences industry. It will be housed in its own building, currently under construction as part of a broad new campus neighborhood for engineering and environmental studies.

ODBI director Clifford Brangwynne said that bioengineering research at Princeton begins with curiosity. "If a cell is a machine, it is unlike any other machine you have encountered," he said. "It is a wet, squishy, almost infinitely complex machine. We need engineering concepts and tools to study these systems."

Allowing engineers to immerse themselves in the mystery of how life works, instead of launching directly into devising new technologies, can yield more creative and effective solutions, said Brangwynne, the June K. Wu '92 Professor of Chemical and Biological Engineering. But ultimately, drawing out those new technologies is essential to the institute.

"How can these insights we are acquiring be useful for my grandfather's dementia, my cousin's cancer, my best friend's severe burn?" Brangwynne said. "How can these engineering approaches, tools, and technologies we are developing help better human lives and improve health, wellness, materials, the environment — and all the challenges humans face?"

Research in the Omenn-Darling Bioengineering Institute includes three intersecting areas: cellular bioengineering, which examines physical processes within cells and where those processes could be adjusted to treat disease and make useful products; device engineering, which includes tools that help researchers visualize, sense, and control the workings of cells; and computational bioengineering, which involves applying data science tools and large-scale computation to bioengineering. (See examples on the following pages.)

Princeton University President Christopher L. Eisgruber '83 said the gift from Omenn and Darling reflects their dual strengths as leaders in biomedical research and public policy.

Darling was one of the first women to earn a graduate degree from what is now Princeton's School of Public and International Affairs, earning a master's of public affairs in 1970. She worked in senior leadership at Boeing and served in numerous national and state policy roles, including the White House, the United States Senate, and numerous nonprofit organizations. Omenn, who is the Harold T. Shapiro Distinguished University Professor at the University of Michigan, served as dean of the University of Washington School of Public Health and CEO of the University of Michigan Health System, and directs Michigan's Center for Computational Medicine and Bioinformatics.

"Given Gil and Martha's exceptional leadership and their scientific and policy achievements, it is especially fitting that the Omenn-Darling Bioengineering Institute will be named for them," Eisgruber said. "This new institute will amplify the University's strengths at the intersection of engineering, machine learning, public policy, and natural sciences, with interdisciplinary collaboration yielding significant benefits to human health and the environment." E

Clifford Brangwynne. Photo by Denise Applewhite

THE MATERIALS SCIENTIST WHO UPENDED CELL BIOLOGY

by Scott Lyon

The conventional view of how living cells are organized has changed dramatically over the past decade.

Clifford Brangwynne, the June K. Wu '92 Professor of Chemical and Biological Engineering, has played a starring role in that revolution.

Starting with a 2009 paper, his research began fusing molecular biology and materials science, leading to foundational insights about the physics of tiny cellular compartments known as organelles and suggesting new ways to treat diseases such as cancer, ALS, and Alzheimer's.

Before that breakthrough, scientists viewed organelles like soap bubbles, with a distinct membrane separating inside from out. Brangwynne and his then-adviser Anthony Hyman showed that many structures within cells are more like raindrops, where biomolecules condense from their surroundings and band together — no membranes, no skins.

At first, the finding made only a quiet impression on the scientific world. When Brangwynne joined the Princeton chemical and biological engineering faculty in 2011, the paper had garnered fewer than 10 citations. But he and his colleagues have since produced a steady flow of research that extends the original finding and demonstrates far-reaching implications for cell biology, bioengineering, and biomedicine. A community of scientists took note and began to contribute to the growing field. Today, a search for "biomolecular condensates" or "membraneless organelles," as these compartments are called, returns more than 40,000 research results in Google Scholar.

Early follow-up work linked this phenomenon to neurodegenerative diseases. More recently, it was linked to gene expression and gene regulation, perhaps the most fundamental mechanisms of life. Brangwynne, now director of the Omenn-Darling Bioengineering Institute, has pointed to these milestones as critical in the development of the field, inflection points that led to its expansion across a wide range of disciplines and application areas including protein aggregation, the immune response to viruses, cell growth, cancer, and a host of other processes.

Today, Brangwynne focuses his energy not only on his group's research program but on cultivating and training the talented researchers who will continue advancing the field and its possibilities. Recently, early-career scientists who have trained in his lab have gone on to fill top academic positions and win some of the most competitive fellowships in the life sciences.

"It's all about the trainees," he said. "That's what I'm most proud of." E

RAISING BIOELECTRIC SHEEPDOGS TO HERD FLOCKS OF CELLS

by Wright Señeres

Daniel Cohen (right) and his research team are creating devices that use electricity to herd communities of cells. Photo by Tori Repp/Fotobuddy

Groups of cells often move like flocks of sheep when healing wounds or building new tissue. So, would it be possible to build a cellular sheepdog?

In Daniel Cohen '08's lab, researchers hope their quest for a bioelectric shepherd will lead to faster wound healing and new treatments for patients.

Cohen, an assistant professor of mechanical and aerospace engineering, is taking advantage of electricity that the body already generates on its own. On the cellular scale, all wounds have a very small electric field. Communities of cells are known to use electric fields to navigate as they move. Cohen and his group have been creating small devices to do the same.

With one such device small enough to fit inside a Petri dish, Cohen's team has guided groups of cells to move and change directions. The device exposes the cells to an electric field. Using computer programming, the researchers change the field's orientation, and the cells migrate in response. In one set of published results, the researchers made groups of cells turn 90 degrees, like drawing with an Etch-A-Sketch toy.

"This device gives us an amazing level of control over cells that we wouldn't have expected to be possible, especially with thousands of neighboring cells executing these maneuvers on command," Cohen said.

This work speeding cellular migration is still in its early stage, but Cohen believes it will lead to significant uses, such as a bioelectric bandage that guides and accelerates wound healing.

One obstacle still to overcome: how to deal with mature skin cells, which Cohen and his group have observed to resist the bioelectric sheepdog. "What we think is happening is the collective behaviors in tissue are fighting with external commands," said Cohen.

In mature tissue, the cells are more tightly bound to each other. The lab team has been able to overcome this resistance by temporarily disrupting their collective behavior using drugs to target how they 'hold hands.' Then the sheepdog can move the cells as before, getting closer to a bioelectric Band-Aid.

For Cohen, success goes beyond useful results; it also means conveying the joy of discovery to others. Cohen leads a storytelling workshop for graduate students and postdocs called Lab Tales. "Integrating storytelling into science communication increases engagement, a sense of inclusion, and trust in science and the scientist," he said. **E**

TRANSFORMING MICROBES INTO FACTORIES FOR THE FUTURE

by John Sullivan

In a darkened room in Hoyt Laboratory, small vats sit under an ultraviolet lamp. In the future, one might replace the steel girders of a refinery; another, sweeping acres of corn.

"Our aim is to move away from petroleum and use living cells to create the fuels, drugs, and chemicals that we need," said José Avalos, an associate professor of chemical and biological engineering and the Andlinger Center for Energy and the Environment. "Instead of extracting natural products from plants, which require land and fertilizer, we are interested in producing them with microorganisms."

Much of Avalos' current work involves yeast, the simple, single-celled organism behind bread and beer. His research team is pulling these ancient technologies into the 21st century, engineering processes that use yeast to create biofuels, industrial chemicals, and drugs.

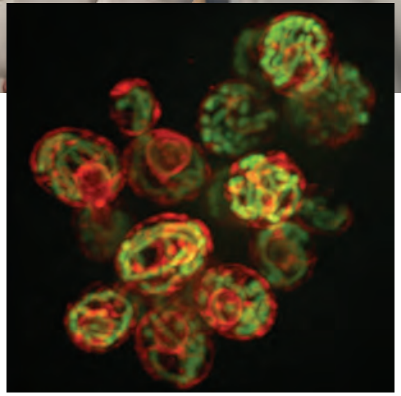
They accomplish this by manipulating cellular metabolism to create microorganisms that produce desired chemicals and proteins. Their tools involve controlling space and time. Time means controlling the sequence in which microorganisms turn on the genes required to produce chemicals. The key is optogenetics, the technique of introducing light-sensitive proteins into microorganisms. Optogenetics allows the researchers to turn chemical production on and off by shining lights into bioreactors.

At the same time, researchers control space by isolating areas for different steps of the metabolic process. They may cluster yeast strains, with each strain contributing a different chemical that acts as a step in a greater production. Or they may use cellular components, called organelles, for different processes in the cell.

"We can run a fermentation in which we have two or more strains that collaboratively work to produce a chemical of interest," Avalos said. "Inside the cell, mitochondria and other organelles are separate areas where you can carry out reactions separate from the rest of the cell."

The breadth of research lends itself to collaboration, and Avalos is working with research teams across the University. Among others, he partners with Clifford Brangwynne and Daniel Cohen on cellular condensates, Claire White on new biocements, Peter Jaffé on environmental cleanup, and Jared Toettcher on optogenetics.

"The holy grail is to establish closed-loop controls of metabolism," he said. "Like setting the thermostat in your house: You set the optimal temperature, and it automatically controls your heater. In yeast, you set the operating conditions and the organism gives you what you need." **E**



Above: José Avalos (center) in the laboratory with graduate students Sarah Kwartler (left) and José Montaño-López (right). Photo by Adena Stevens

Right: Yeast cells showing mitochondria (green) and endoplasmic reticulum (red) interacting. These are two key organelles targeted in the Avalos lab for chemical production. Image courtesy of the researchers

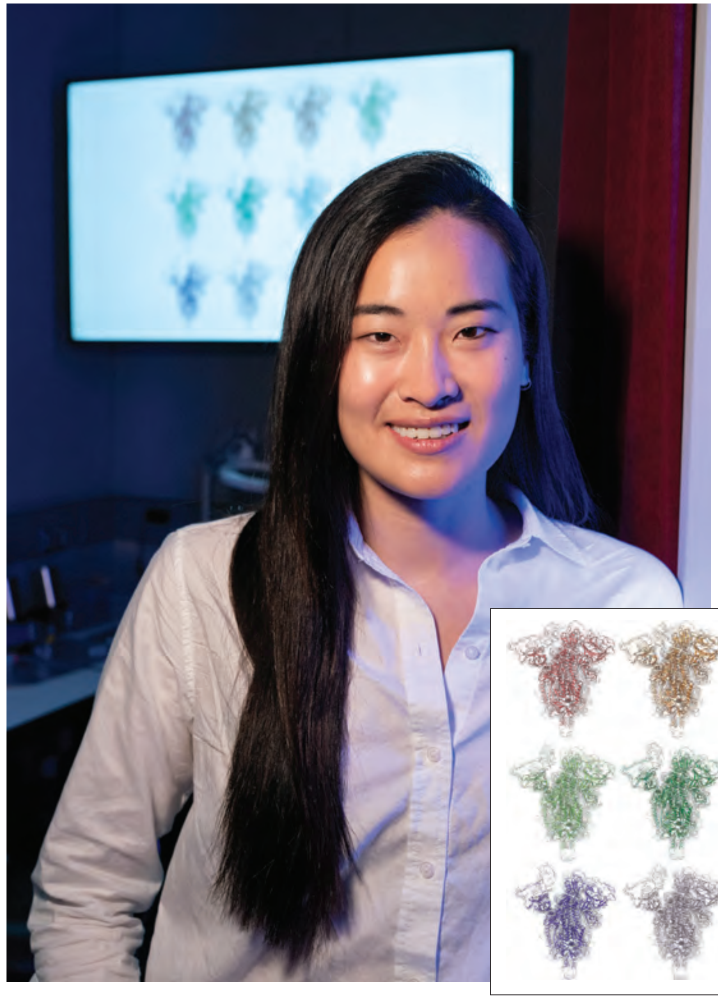
USING COMPUTER **VISION** TO SEE **PROTEINS**

by Julia Schwarz

Ellen Zhong's research creates detailed images of proteins and cells. But she isn't using a microscope or a camera. She uses algorithms.

Zhong, an assistant professor of computer science, uses the tools of machine learning and computer vision to construct images from cryogenic electron microscopy (cryo-EM) experiments. Each cryo-EM experiment, she said, produces millions or even tens of millions of raw images. Her algorithms process this raw data to create clear, high-resolution images.

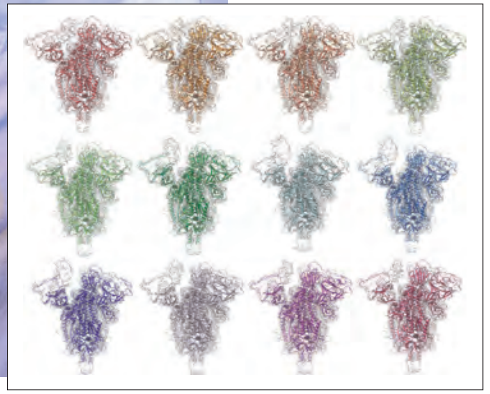
"The computational work," Zhong said, "is crucial for extracting the signal from the noise."



One example of this computational work is a method recently developed by Zhong and her collaborators, a technique called cryoFIRE. Their method can process image data exponentially faster than previous techniques, and without any loss of accuracy, lowering the computational burden required to create detailed images from each experiment. Advances like these, she said, make it easier, faster, and less expensive for researchers to process cryo-EM data.

Zhong's own work primarily focuses on data related to protein structures, though the techniques she is developing can be applied to any type of cryo-EM experiments. Detailed images of proteins are critical, Zhong said, because understanding structure is essential to understanding function. Proteins are remarkably consistent in their shapes, so when they vary even slightly that variation can provide clues into their unique capability or function. Understanding protein structures has led to advances in antibody therapies and other medical applications.

The cryo-EM imaging field is also on the cusp of a very exciting leap right now, according to Zhong, because it's recently become possible to "look directly inside cells," instead of just at individual molecules like proteins or DNA. How individual molecules within a cell work together and interact is still largely a mystery, Zhong said, so getting a snapshot of what is happening inside a cell opens up exciting new possibilities for research across disciplines in bioengineering. **E**



Above: Ellen Zhong. Photo by Tori Repp/Fotobuddy Right: Atomic models of different conformations of the SARS-CoV-2 spike protein created using cryoDRGN, an algorithm built by Zhong and her colleagues to process cryo-EM images. Image courtesy of Ellen Zhong

CHANNELING **THE CELL'S SKELETON** INTO A NIMBLE **NANOMACHINE**

by Molly Sharlach

In every one of our cells, a humble protein called tubulin assembles by the thousands into a precise helical pattern with a big purpose.

Among other essential functions, these structures direct the life-giving process of cell division and enable immune cells to crawl into wounded tissue.

Now, Princeton researchers who've uncovered foundational rules about how these structures form are taking their knowledge a step further. They are building nanorobots inspired by the biology.

"We thought, why only use [our techniques] to understand what the cell is doing? Can we use them to make something that didn't exist before? Can we create some new technology?" said Sabine Petry, an associate professor of molecular biology.

Petry's research group has long collaborated with fluid mechanics expert Howard Stone, the Donald R. Dixon '69 and Elizabeth W. Dixon Professor of Mechanical and Aerospace Engineering, on studies of how tubulin helices form hollow rods called microtubules, as well as their mechanics and their roles in living cells.

Inspired by the extraordinary length and specialized functions of microtubules in nerve cells' axons — the long cables that carry nerve impulses around the body — Stone and Petry sought to harness microtubules' circuit-like behavior to build nanomachines, with potential applications in soft robotics, materials science, and medical diagnostics.

In 2021, they received a grant from Princeton's Eric and Wendy Schmidt Transformative Technology Fund, and hired two postdoctoral fellows with complementary expertise: Ryungeun Song, a mechanical engineer who had focused on microfluidics in his graduate work; and Meisam Zaferani, a biophysicist who had studied the cues that help mammalian sperm cells navigate toward an egg.

Through simulations and experiments, Song and Zaferani have built devices with narrow channels and tested how different geometries impact the growth of microtubules. From there, they are beginning to test how bespoke architectures can create microtubules that act as useful machines for transporting and sensing molecules on a chip.

"Over a billion years of evolution, biological processes have evolved many different approaches to use these cytoskeletal elements," said Zaferani, a Gilbert S. Omenn, MD. '61 and Martha A. Darling *70 Fellow in Molecular Biology. "We're trying to simulate that using our technology."

Stone, who frequently collaborates with Princeton colleagues in both engineering and the natural sciences, said, "I find it very interesting to find problems that involve fluid mechanics in other fields, because often I find a topic that is poorly understood to the scientists on the other side and poorly understood by myself, and together we work to figure it out." **E**

Postdoctoral fellows Meisam Zaferani (left) and Ryungeun Song are building microfluidic devices to harness the capabilities of microtubules. Photo by Sameer A. Khan/Fotobuddy

SIMULATIONS REVEAL WORKINGS OF DROPLETS THAT UNDERLIE LIFE'S FUNCTIONS

by Molly Sharlach

Jerelle Joseph (third from right) and her team use computer simulations to examine the formation of biomolecular condensates. Photo by Sameer A. Khan/Fotobuddy

In living cells, molecules can come together through a dynamic, transient process, forming droplets that hold the components needed for a specific job.

Once they come together, these molecular assemblies can break down nutrients, send signals to neighboring cells, or turn on stress responses.

Jerelle Joseph seeks to uncover the rules behind the formation and evolution of these droplets, known as biomolecular condensates.

"These membraneless structures are liquid-like. They exhibit characteristics like flowing, dripping, and fusing," and form by phase separation — like oil droplets in water, said Joseph, who joined Princeton in January 2023 as an assistant professor of chemical and biological engineering.

"What makes them very exciting," both to study and potentially to engineer, said Joseph, "is that they have vast functions and implications for health and disease."

Joseph's team uses computer simulations to examine the formation of biomolecular condensates — droplets that contain hundreds of protein molecules, and sometimes DNA or RNA, and play roles in regulating growth, metabolism, and more.

Researchers' understanding of biomolecular condensates has come a long way since Princeton professor Cliff Brangwynne and others first described the emergence of these cellular compartments nearly 15 years ago (see page 13). Still, many questions remain about the conditions that drive condensates to form, and how they change over time.

"If we can understand how condensates form and are regulated, we can engineer them," said Joseph. "Essentially, we want to reverse-engineer condensates to find out how they come about. And also, forward-engineer them to create new functionalities within cells or to prevent unwanted functions," such as cancer or neurodegenerative diseases. Joseph is also excited by the possibility of engineering plant metabolism for sustainable food production.

But before these applications can come to fruition, Joseph and her team must develop computational models that are accurate enough to faithfully represent organization within living cells, yet efficient enough to run on today's computers.

A growing body of experimental data on how condensates form and change is crucial to grounding her team's models, said Joseph. Her postdoctoral work at the University of Cambridge included developing simulations to predict the phase separation of proteins, achieving a new degree of accuracy.

"Now, we want to be able to describe a wider breadth of proteins as well as nucleic acids that undergo phase separation such as RNA. So, we need to be able to augment and enhance our approaches to better describe more complex systems," she said. **E**

SPATIAL DATA ADDS 'GREAT NEW DIMENSION' TO STUDIES ON CANCER AND DEVELOPMENT

by Molly Sharlach

To examine the body's tapestry of cells, scientists have historically mounted thin sections of tissue on microscope slides, zooming in to study muscles and neurons and identify the hallmarks of disease.

Recent decades have brought revolutions in high-throughput sequencing that allow researchers to measure not only the genome of a biological sample, but also the set of genes that are active in the tissue at a given point in time. And with further advances, this gene activity can now be localized to small clusters of cells — generating remarkable volumes of data that present new computational challenges.

Ben Raphael has made it his mission to create new ways of understanding these reams of data. A professor of computer science who has long specialized in cancer genomics, Raphael has become an expert interpreter of experiments that sequence the genes expressed in a tissue sample while retaining spatial information.

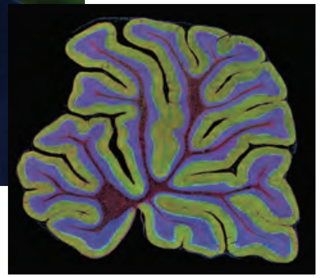
"Biology happens in physical space," said Raphael. But until recently, high-throughput sequencing required researchers to grind up tissues into thousands of separated cells. "It's strange that in genomics we have long been ignoring space."

Now, researchers can preserve spatial information, which can show in unprecedented detail, for example, the locations of tumor cells in relation to connective tissue, blood vessels, and immune cells — which could potentially guide decisions like whether to pursue immunotherapy treatment for a patient with cancer, said Raphael.

As cells divide and move over time, the technology can also keep track of cells' origins and illuminate the dynamics of cancer, as well as the development of healthy tissues. Raphael's research group is collaborating with Michelle Chan, assistant professor of molecular biology and genomics at Princeton, to establish methods to trace cellular lineages in animal development.

In another collaboration supported by the Princeton Branch of the Ludwig Institute for Cancer Research, Raphael's team is working with Joshua Rabinowitz, a professor of chemistry and genomics, to quantify metabolite levels in the liver's various cells. Raphael's group is using data from the Rabinowitz lab to create topographic-like maps of the liver, showing the gradients of certain carbohydrates or fat molecules over the organ's maze of veins and lobules.

"We're interested in all the interactions happening between cancer cells and normal cells that are either supporting the cancer's growth or suppressing it," said Raphael. "Being able to look in the spatial context where interactions occur is a great new dimension." **E**



Ben Raphael (above) and his research team are developing computational methods to interpret data about when and where genes are active in tissue samples. Their studies have explored tissues such as the accordion-like layers of the cerebellum, the brain's locomotion control center. Image by Thomas Deerinck, National Center for Microscopy and Imaging Research, University of California-San Diego; photo of Raphael by David Kelly Crow

BIOENGINEERING POSTDOC **LINNEA LEMMA** SELECTED FOR **PRESTIGIOUS FELLOWSHIP**

by Wright Señeres

The Howard Hughes Medical Institute (HHMI) has named Princeton postdoctoral researcher Linnea Lemma a 2023 Hanna Gray Fellow, supporting her research on internal components of cells that facilitate photosynthesis.

The HHMI Hanna H. Gray Fellows Program supports researchers from underrepresented groups who have the potential to become academic leaders, providing each fellow with up to $1.5 million over eight years. The support comes at a critical time in these scientists' careers — the transition from student to postdoctoral researcher to principal investigator — often seen as a bottleneck in the academic pipeline. HHMI's 2023 cohort of Hanna Gray fellows includes 25 scholars from 18 institutions.

Linnea Lemma. Photo by Sameer A. Khan/Fotobuddy

At Princeton, Lemma is working in the labs of two HHMI Investigators: her adviser Martin Jonikas, associate professor of molecular biology, and Clifford Brangwynne, the June K. Wu '92 Professor in Engineering and professor of chemical and biological engineering.

Lemma investigates the connection between living cells' energy use and their internal organization. Specifically, she studies a part of algae cells called the pyrenoid that concentrates carbon dioxide to enhance the photosynthesis process. Scientists believe pyrenoids enhance plants' efficiency in converting carbon dioxide from the air into sugar, thereby acting as an essential component of the global carbon cycle.

A physicist by training, Lemma came to Princeton in 2021 following her Ph.D. at Brandeis University and her undergraduate degree from Johns Hopkins University. She was jointly appointed to three labs: the Jonikas lab, the Brangwynne lab, and the lab of Ned Wingreen, the Howard A. Prior Professor in the Life Sciences and professor of molecular biology and the Lewis-Sigler Institute for Integrative Genomics.

At the new Omenn-Darling Bioengineering Institute at Princeton, Lemma is one of five inaugural Omenn-Darling Bioengineering Institute - Innovators (ODBI2) Distinguished Postdoctoral Scholars. Along with Lemma, the ODBI2 Scholars are Pedro de Souza, Long Nguyen, Pengfei Zhang and Hongbo Zhao.

ODBI is also the home of the Gilbert S. Omenn '61 and Martha A. Darling *70 Fellowship program. The inaugural Omenn-Darling Fellows are Jaewan Jang, Sara Kacmoli *23, and Meisam Zaferani (see page 17 for a description of Zaferani's research). **E**

PROBING **BACTERIAL PERSISTENCE** TO **BATTLE SUPERBUGS**

by Molly Sharlach

Persistence is a lauded trait among humans, but when it comes to the bacteria that infect us, persistence can be a major problem.

Antibiotics wipe out most bacteria causing an infection. But because the drugs often target the processes behind bacterial growth, slow-growing cells can sometimes dodge the antibiotic attack. Those surviving cells, called persisters, are distinct from cells with heritable resistance mutations. Evidence shows that persisters can have higher mutation rates than their susceptible neighbors, which can spur the development of resistance in a population of bacteria.

Tolerance mutations that slow growth and increase antibiotic persistence are "like a stepping stone to resistance," said Mark Brynildsen, a professor of chemical and biological engineering. "So, if tolerance mutations are a stepping stone, you can actually try and impair those to stop resistance before it even gets started."

Brynildsen's research group is working to understand the origins of persisters and identify their weaknesses. The lab's discoveries have elucidated survival tactics of persisters that could inform more effective therapies to help curb antibiotic resistance.

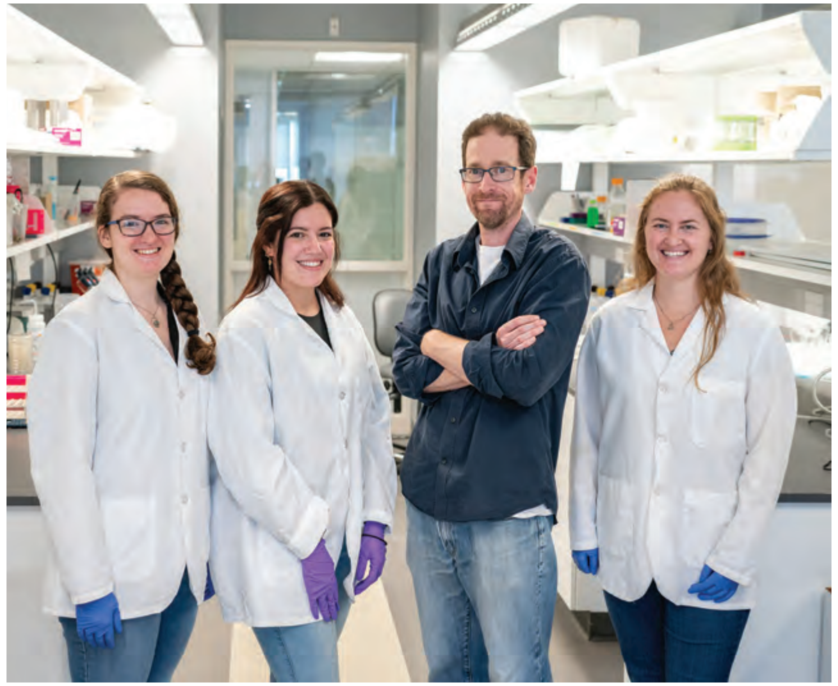
Each bacterial cell typically contains a single copy of its chromosome, but at different growth stages some cells can hold numerous copies, affording them backups in case one of their genomes crashes — for instance, from DNA damage.

Brynildsen's team has studied the antibiotic persistence pathways of bacterial cells with different chromosome numbers. They've found that cells with a single chromosome copy are hard-pressed to become persisters when faced with antibiotics that damage DNA, compared to cells with two or more copies. Further, persisters with a single copy depend on different factors to survive antibiotic treatment.

His lab is also looking into persistence and the development of antibiotic resistance under conditions of nutrient deprivation. Compared to the rich growth media typically used for such experiments, these conditions more closely reflect the environment of a person's urinary tract or other infection site.

"If the antibiotic treatment happens in populations that for one reason or another are in growth stasis — if you don't have sugar available or you're low on iron or sulfur, how does that impact the bacterial response to these stresses?" said Brynildsen.

Armed with a background in metabolic engineering and bacterial stress responses, his group is investigating which genetic factors play a role in persistence when nutrients are limited. In a way, knowing the pathways that lead to problematic mutations under realistic infection conditions is as important as knowing the final mutations, said Brynildsen, because understanding routes to resistance could provide new avenues for therapeutic interventions. **E**



Professor Mark Brynildsen (second from right) with Ph.D. students (from left) Katherine Sniezek, Nashaly Soto-Echevarria, and Gabrielle Leon. Photo by Tori Repp/Fotobuddy

BRIDGING EXPERIMENTS AND DATA SCIENCE TO DECODE THE GENOME

by John Sullivan

What differences cause a cell to function as a tough muscle strand in the heart as opposed to a gossamer neuron in the brain or an immune cell protective of infections and cancers?

For Yuri Pritykin *14, the answer lies somewhere in the genome, an enormous, winding code whose combination of simple instructions spells out the infinite complexity of life. Pritykin, an assistant professor of computer science and genomics, is working to better understand the code and to examine ways that alterations in its expression lead to starkly different results. Ultimately, this knowledge could unlock the key to improving health and treating disease.

"The cells in complex organisms are very different," Pritykin said. "The same genes are encoded in each cell, but the functions are different based on which genes are expressed."

Currently, his research group's focus is on immunology, particularly a class of immune cells called T cells that play a critical role in cancer and autoimmune diseases.

"But most of the computational approaches that we apply can be used at least in principle to analyze data in other types of cells as well," he said.

Yuri Pritykin. Photo by Sameer A. Khan/Fotobuddy

Pritykin's team has developed a number of tools widely used by researchers. One, called GuideScan, helps researchers precisely aim the CRISPR enzyme that has revolutionized genetic engineering. The CRISPR enzyme neatly snips DNA strands, allowing researchers to analyze and combine elements of the genome. Although simple in principle, aiming CRISPR is challenging because the genome is 3.2 billion nucleotides long.

Scientists use another molecule called a guide RNA, to direct the CRISPR to the target section of the DNA. The scientists aim the guide by adjusting a 20-nucleotide sequence in the guide RNA. But this task is complicated by the tendency of guide RNA to hit close matches along the genome as well as the desired target.

"The design of the guide RNA is an interesting computational problem," Pritykin said. "We want to hit what we target and not to hit anywhere else."

By carefully structuring data for fast analysis, GuideScan transformed a laborious, time-consuming process into a simple operation. This is particularly important for experiments involving hundreds or thousands of CRISPR edits.

As a computational biologist, Pritykin's research straddles the divide between the terminals of data scientists and the labs of traditional biology. His team designs experiments to study gene expression, and also creates algorithms and methods to interpret the massive data sets generated by the experimental work.

"The distinction between computation and wet lab is becoming not as sharp as it once was," Pritykin said. "Knowing the biology is essential, but knowing the math and computer science is also essential." **E**

ADVANCED OPTICS REVEAL HOW CELLS AND MOLECULES SQUIRM, PULSE, AND OOZE

by John Sullivan

At first glance, the cancer cell appears as a bright dot on the computer screen, but when Tian-Ming Fu zooms in, he opens a new world.

No longer static, the cell squirms and pulses as it creeps along a blood vessel inside a zebrafish. A barbed tentacle extrudes from the cell and flails rapidly as the cell oozes along the bloodstream. Finally, the cell hooks the vessel and pulls itself in. The cell presses against the vessel wall.

"It wants to stick," said Fu. "The cancer cell wants to find the loophole, so it can get out of the blood vessel."

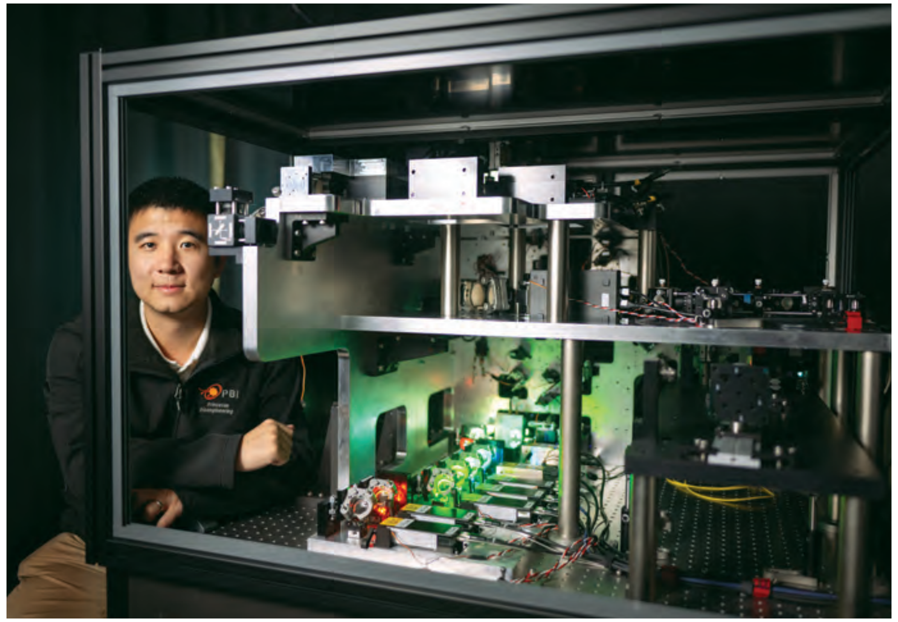
Fu, an assistant professor of electrical and computer engineering and the Omenn-Darling Bioengineering Institute, is pioneering a new science of cellular imaging, one that allows researchers to observe cells in their natural environment with high resolution. For centuries, our understanding of cells was based on static, two-dimensional images. As fundamental as they were for building modern biology, the images were limited by the technology used to create them. Now, scientists like Fu are combining advanced optical and computational methods to create three-dimensional, dynamic movies of cellular behavior within multicellular organisms.

"Biology and biomedicine have seen a lot of revolutions in recent decades, in genetics, biochemistry, structural biology," Fu said. "A huge thing that is largely missing from this picture is the dynamics. In the end, life is defined by its animated nature."

Fu uses adaptive optics, a technique originally developed by astronomers peering through the earth's atmosphere, to create clear images inside multicellular organisms such as zebrafish and mice. The images and video allow scientists to observe cellular behaviors and interactions with unprecedented resolution. The technique also offers new insight into the mechanisms that drive the interactions. For example, the researchers can capture the dynamics of the cancer metastasis process inside a blood vessel, which can provide vital clues about how cancers spread through the body.

Besides cellular behavior, Fu is using the technique to study proteins and other molecules inside cells. His research team is developing new electronic devices to manipulate and study molecules in their native environment. The dynamics of molecules in space and time are critical in understanding biology, Fu said. Most organisms are made of the same basic chemicals, but it is how those chemicals behave and react in space and time that determines the nature of the organism.

"Most of the fundamental molecules across cells and species are the same, but the dynamics can be quite different," Fu said. "In the end, it is how these molecules act in space and time that makes us human and a fish, a fish." **E**



Tian-Ming Fu is pioneering a new science of cellular imaging that allows researchers to observe cells in their natural environment with high resolution. Photo by Sameer A. Khan/Fotobuddy

RECENT FACULTY AWARDS, PROMOTIONS, AND HONORS


Elke Weber. Photo by David Kelly Crow


Glaucio Paulino. Photo by Sameer A. Khan/FotoBuddy


Sujit Datta. Photo by David Kelly Crow


Felix Heide. Photo by David Kelly Crow

ANDLINGER CENTER FOR ENERGY AND THE ENVIRONMENT

Elke Weber
Patrick Suppes Prize in Psychology, American Philosophical Society

CHEMICAL AND BIOLOGICAL ENGINEERING

Clifford Brangwynne
Dickson Prize in Medicine, University of Pittsburgh

Tsuneko & Reiji Okazaki Award, Nagoya University

Raymond and Beverly Sackler International Prize in Biophysics, Tel Aviv University

Pierre-Thomas Brun
Early Career Award for Soft Matter Research, American Physical Society

Sujit Datta
Alan P. Colburn Award for Excellence in Publications by a Young Member of the Institute, AIChE

Early Career Award for Biological Physics, American Physical Society

Arthur B. Metzner Early Career Award, The Society of Rheology

Emily Davidson
Alfred Rheinstein Faculty Award

Pablo Debenedetti
Aneesur Rahman Prize for Computational Physics, American Physical Society

David Graves
Plasma Materials Science Hall of Fame Prize, Nagoya University

Yannis Kevrekidis
William H. Walker Award for Excellence in Contributions to Chemical Engineering Literature, AIChE

Rodney Priestley
Eminent Chemical Engineers Award, AIChE Minority Affairs Community

Robert Prud'homme
Fellow, National Academy of Inventors

Michele Sarazen
35 Under 35, AIChE

Michael Webb
CAREER Award, National Science Foundation

CIVIL AND ENVIRONMENTAL ENGINEERING

Branko Glišić
Chair, Department of Civil and Environmental Engineering

Denise Mauzerall
William S. Tod Professor of Civil and Environmental Engineering and Public and International Affairs

Reed Maxwell
William and Edna Macaleer Professor of Engineering and Applied Science

Reza Moini
CAREER Award, National Science Foundation

Glaucio Paulino
A.C. Eringen Medal, Society of Engineering Science

COMPUTER SCIENCE

Danqi Chen
AI Researcher of the Year, Samsung

CAREER Award, National Science Foundation

Adji Bousso Dieng
AI2050 Early Career Fellowship, Schmidt Futures

Sloan Research Fellowship, Alfred P. Sloan Foundation

Felix Heide
Significant New Researcher Award, ACM SIGGRAPH

Sloan Research Fellowship, Alfred P. Sloan Foundation

Jonathan Mayer '09
William G. Bowen Presidential University Preceptor

CAREER Award, National Science Foundation

Andrés Monroy-Hernández
E. Lawrence Keyes, Jr./Emerson Electric Co. Faculty Advancement Award

Karthik Narasimhan
CAREER Award, National Science Foundation

Ravi Netravali
Howard B. Wentz, Jr. Junior Faculty Award

Yuri Pritykin *14
CAREER Award, National Science Foundation

Jennifer Rexford '91
Provost

Szymon Rusinkiewicz
Chair, Department of Computer Science

William R. and Jane G. Schowalter Fund Award

Jaswinder Singh '87
Professor of Computer Science, Technology, and Societal Change

ELECTRICAL AND COMPUTER ENGINEERING

Maria Apostolaki
Research Scholar Award, Google

Minjie Chen
Richard M. Bass Outstanding Young Power Electronics Engineer Award, IEEE Power Electronics Society

Nathalie de Leon
Experimental Physics Investigator, Gordon and Betty Moore Foundation

Rolf Landauer and Charles H. Bennett Award in Quantum Computing, American Physical Society

Jaime Fernández Fisac
Research Scholar Award, Google

Chi Jin
CAREER Award, National Science Foundation

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

Barry Rand *07
Experimental Physics Investigator, Gordon and Betty Moore Foundation

Jeff Thompson
Experimental Physics Investigator, Gordon and Betty Moore Foundation

Gerard Wysocki
Optica Fellow

MECHANICAL AND AEROSPACE ENGINEERING

Emily Carter
William H. Nichols Medal, American Chemical Society

Luc Deike
François Frenkiel Award for Fluid Mechanics, American Physical Society

Kelsey Hatzell
Alfred Rheinstein Faculty Award

Young Investigator Program Award, Office of Naval Research

Marcus Hultmark *09
Experimental Physics Investigator, Gordon and Betty Moore Foundation

Naomi Leonard '85
Chair, Department of Mechanical and Aerospace Engineering

Anirudha Majumdar
Sloan Research Fellowship, Alfred P. Sloan Foundation

Young Investigator Program Award, Office of Naval Research

Julia Mikhailova
Experimental Physics Investigator, Gordon and Betty Moore Foundation

Michael Mueller
Fellow, American Society of Mechanical Engineers

Alexander Smits
Officer of the Order of Australia

OPERATIONS RESEARCH AND FINANCIAL ENGINEERING

Amir Ali Ahmadi
Kavli Fellow, National Academy of Sciences

Matias Cattaneo
Fellow, American Statistical Association

Jason Klusowski
CAREER Award, National Science Foundation

Howard B. Wentz, Jr. Junior Faculty Award

William Massey '77
Member at Large, American Mathematical Society Council

Bartolomeo Stellato
CAREER Award, National Science Foundation

Franco Strazzabosco Award, Italian Scientists & Scholars in North America Foundation

Ludovic Tangpi
Claytor-Gilmer Fellowship, American Mathematical Society


Nathalie de Leon. Photo by Sameer A. Khan/Fotobuddy


Michael Mueller. Photo by David Kelly Crow


Ludovic Tangpi. Photo by David Kelly Crow

ENGINEERING FACULTY RECOGNIZED FOR EXCELLENCE IN TEACHING, SERVICE, AND MENTORSHIP

Five Princeton Engineering faculty members were honored this year for outstanding teaching, service, and mentorship.

Richard Register. Photo by David Kelly Crow

Richard Register *86, the Eugene Higgins Professor of Chemical and Biological Engineering (CBE) and director of the Princeton Materials Institute, received the SEAS Faculty Distinguished Service Award.

CBE department chair Christos Maravelias wrote that Register "has been an extraordinary University citizen," serving the department, the engineering school, and the University in multiple roles since joining Princeton in 1990.

Robert Vanderbei. Photo by David Kelly Crow

Robert Vanderbei, a professor of operations research and financial engineering (ORFE), was the recipient of the SEAS Excellence in Mentoring Award. He chaired the ORFE department from 2005 to 2012, and has served as the department's director of undergraduate studies.

Vanderbei's former Ph.D. students emphasized his generosity and ongoing commitment to their success. "It has been the privilege of a lifetime to learn from Bob, to work with him, and to count him among my friends," an advisee wrote.

Claire White. Photo by Sameer A. Khan/ Fotobuddy

Claire White, an associate professor of civil and environmental engineering and the Andlinger Center for Energy and the Environment, was one of four recipients of the University-wide President's Award for Distinguished Teaching.

White imparts her pioneering knowledge of sustainable materials with a consistently engaging and innovative approach to learning that "turns cement into magic," in the words of one student. "I've had the opportunity to sit in on a few of her lectures, and I can't forget her flawless ability to engage and keep the audience captivated," said a postdoctoral researcher.

Amir Ali Ahmadi. Photo by Frank Wojciechowski

Amir Ali Ahmadi, a professor in the ORFE department and director of the Program in Optimization and Quantitative Decision Science, received the engineering school's annual Distinguished Teaching Award. Presenting the award at the school's May 29 Class Day ceremony, Vice Dean Antoine Kahn *78 said that students have repeatedly recognized Ahmadi as being among the school's top teachers and his courses are quickly filled.

"As a faculty member, there is nothing more rewarding than being recognized by your students," Kahn said. He said that one student described Ahmadi as "patient, warm, and deeply concerned with the well-being of his students."

Luc Deike. Photo by Sameer A. Khan/ Fotobuddy

Luc Deike, an associate professor of mechanical and aerospace engineering and the High Meadows Environmental Institute, was one of four recipients of the 2023 Graduate Mentoring Awards from the McGraw Center for Teaching and Learning.

Several students praised Deike for sensing when they felt overwhelmed and offering them reassurance. One student recalled meeting with Deike after coming up short on some research goals. "I remember trying to act like everything was fine," the student commented. "Luc saw through to my concerns and told me to focus on my classes, assuring me that we would figure out the research later. While it seems like such a small thing in retrospect, it meant a lot to me at the time. Since then, I've seen that Luc has an uncanny ability to sense when I am frustrated with myself and then offer encouragement."

GRADUATES RECOGNIZED AT CLASS DAY FOR RESILIENCE, DEDICATION, AND PERSEVERANCE

Dean Andrea Goldsmith welcomed graduates, parents, and friends to the 2023 Class Day ceremony on Monday, May 29, recognizing "the accomplishments and the resilience of this Great Class of 2023."

Faced with the wrenching changes of the COVID-19 pandemic at the beginning of their time at Princeton, the students responded with "courage, determination, creativity, and optimism," Goldsmith said.

"You formed unique bonds with your friends, family, and mentors as we all navigated the tragedy of COVID. My colleagues and I are so deeply impressed with your many successes over the past four years despite the challenges that you faced," Goldsmith, the Arthur LeGrand Doty Professor of Electrical and Computer Engineering, told the audience gathered in the Friend Center courtyard. "Your hard work, dedication, and perseverance are indeed the attributes that led you to Princeton and to your success here, and they will be the foundation for your future success."

With 352 students receiving engineering degrees and 56 receiving bachelor of arts degrees in computer science, the class included 408 students, representing 32% of the University's Class of 2023.

The winners of major awards at the 2023 Princeton Engineering Class Day, as presented by Associate Dean for Undergraduate Affairs Peter Bogucki, were:

J. Rich Steers Award
Thomas Olson
Mechanical and Aerospace Engineering
Michal Kozlowski
Chemical and Biological Engineering

Jeffrey O. Kephart '80 Prize In Engineering Physics
Nicholas Allen
Computer Science

Tau Beta Pi Prize
Bridget Denzer
Chemical and Biological Engineering

Joseph Clifton Elgin Prize
Janelle Arnold
Chemical and Biological Engineering
Karena Yan
Operations Research and Financial Engineering

George J. Mueller Award
Kasey Shashaty
Electrical and Computer Engineering
Maximilian Walther
Computer Science

Calvin Dodd MacCracken Senior Thesis/Project Award
Kristen Ahner
Mechanical and Aerospace Engineering
Jay Kaplan
Chemical and Biological Engineering

Lore von Jaskowsky Memorial Prize
Ashley Cao
Civil and Environmental Engineering
Kyle Ikuma
Mechanical and Aerospace Engineering

James Hayes-Edgar Palmer Prize In Engineering
Jacob Beyer
Electrical and Computer Engineering
Emilio Cano Renteria
Civil and Environmental Engineering

Class of 2023 award winners with Dean Andrea Goldsmith and Distinguished Teaching Award recipient Amir Ali Ahmadi. Photo by Frank Wojciechowski

Jovan Aigbekaen.
Photo by Kevin Birch

SENIOR THESIS BRINGS AN ENGINEER'S INSIGHT TO AIR QUALITY

Jovan Aigbekaen was stuck in Friday afternoon rush hour traffic on Route 1 in New Jersey. For most drivers, this would have been a frustrating, if familiar, inconvenience. But for Aigbekaen, it was a chance to grab some data.

By improving mobile measurements of air quality and geolocating them to sites like highways, buildings, parking lots, and green spaces, Aigbekaen's research for his senior thesis unveiled critical information that could help cities become cleaner and more livable. He put the technology through its proof-of-concept stage in suburban central New Jersey.

"This kind of technology gives us new ways to understand our environment and the dynamic interactions of pollution, built spaces, and transportation," said Aigbekaen. "It's hard to make decisions about cutting carbon emissions or other pollutants without the technology to monitor and measure them."

Affixed to the car with four powerful magnets was a metal box containing a suite of solar-powered sensors to measure pollution, noise, temperature, and humidity — topped by a camera taking nearly 360-degree images of the car's surroundings.

An electrical and computer engineering major with a passion for studying and improving urban spaces, Aigbekaen designed his thesis research to integrate images in new ways with air and noise pollution data, opening possibilities for investigating environmental quality at hyperlocal scales.

Many large cities around the world are studded with air quality monitoring stations, but these have limited ability to track dynamic, fine-scale differences in conditions tied to traffic, green space, buildings, or industrial facilities. This type of monitoring is also relatively rare in developing countries, Aigbekaen noted.

"Cities are always changing and evolving, and the sensing nodes, by being in a fixed position, can't really capture that flux and change," said Aigbekaen, who also earned a certificate from Princeton's Program in Architecture and Engineering. Aigbekaen grew up in Dracut, Massachusetts, about 30 miles northwest of Boston, and said he was always captivated by the vibrance and varied architecture of the city.

By developing technology to sync images with air quality data, he hopes that future work can provide new insights into what factors lead to poor air quality, noise pollution, or heat islands, as well as point to strategies to mitigate these problems. For example, said Aigbekaen, areas near highways or busy roads that also have lots of trees may have lower carbon dioxide levels than similar spaces without vegetation, but these effects need more study.

Over two days last spring, he collected around 200 data points on the Princeton campus and in the surrounding area as a proof of concept for integrating visual images with sensor readings, using his friend's car and a University golf cart driven by a Facilities staff member.

Along with adapting software to transmit and store the data, Aigbekaen used a computer vision technique called semantic image segmentation to categorize all the pixels of each image as greenery, buildings, sky, or vehicles. Then he used computational modeling to assess how well the composition of an image could predict levels of CO_2, particulate matter, and noise pollution.

Even with a relatively small data set as its input, his model was surprisingly effective, especially at predicting CO_2 levels, with just a 2.5% average error rate when using all the available image categorizations. The results "highlighted the utility of this approach — of using all these different environmental metrics for monitoring," said Aigbekaen, whose advisers on the project were Elie Bou-Zeid, a professor of civil and environmental engineering, and Gerard Wysocki, an associate professor of electrical and computer engineering.

In the future, Aigbekaen envisions an even more compact sensing kit that could be worn on someone's clothing, coupled with software for real-time visualization of environmental conditions. He thinks the low cost of the technology could help empower communities that have been overlooked by pollution monitoring. Now a master's student in sustainable design and construction at Stanford University, Aigbekaen said he is interested in pursuing equitable solutions for all communities as renewable energy expands in the coming years.

– by Molly Sharlach

Aigbekaen used a computer vision technique called semantic image segmentation to categorize all the pixels of each image as greenery, buildings, sky, or vehicles. Images courtesy of Jovan Aigbekaen

GRADUATE STUDENT RESEARCH ADVANCES TECHNOLOGY FOR BIOMEDICINE, FUSION ENERGY, AND QUANTUM SENSING

See more profiles of #PrincetonEngineers on Instagram @eprinceton.

Lila Rodgers (right) in the laboratory with her adviser, Nathalie de Leon. Video still courtesy of The Princeton University Broadcast Center

Lila Rodgers
Ph.D. 2023
Electrical and Computer Engineering
Adviser: Nathalie de Leon, Associate Professor of Electrical and Computer Engineering

Rodgers' doctoral dissertation contributed directly to two very different technologies: quantum computers and quantum sensors.

"Quantum systems promise significant technological advances, but they suffer from significant engineering challenges that prevent us from realizing their full potential," she said. "My research focused on improving quantum technologies by correlating materials spectroscopy with quantum measurement."

Rodgers applied her work on spectroscopy and measurement in two distinct quantum systems: nitrogen-vacancy centers in diamonds and superconducting qubits. Rodgers made several key breakthroughs, leading to three patent applications and multiple first-author papers in major journals, including Nature Communications.

Among other projects, she worked to build the world's first-ever confocal microscope inside a cryogenic high vacuum chamber and helped make the first significant breakthrough in superconducting qubit coherence in a decade.

"Lila is an excellent experimentalist and a research powerhouse," said Nathalie de Leon, Rodgers' adviser. "She is fearless in tackling the big, important problems, and she is a broad enough thinker to strategically find these big problems independently."

Earlier this year, Rodgers was named one of four winners of the Porter Ogden Jacobus Fellowship, Princeton University's top honor for graduate students. She is now a technical staff scientist at MIT Lincoln Laboratory.

Francisco Sáenz
Ph.D. Candidate
Mechanical and Aerospace Engineering
Adviser: Egemen Kolemen *08, Associate Professor of Mechanical and Aerospace Engineering and the Andlinger Center for Energy and the Environment

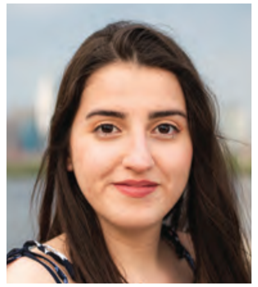
Francisco Sáenz. Photo by Bumper DeJesus

Nuclear fusion, the driving force of the sun and stars, could supply nearly limitless clean energy to society if scientists and engineers develop fusion reactors. But the staggering amount of heat and pressure that fusion generates poses a big problem for metal reactor components, which can melt, erode, and become brittle.

Sáenz believes that liquid metals could solve some of those overheating challenges, since their mobility could allow them to dissipate heat more effectively than solid metals. Working closely with his adviser Egemen Kolemen, Sáenz has studied a concept for fusion reactors he refers to as "divertorlets," which he said would function like small trenches in the reactor components that remove critical heat loads. Divertorlets could allow liquid metals to flow continuously in a circular motion, helping to transfer heat more effectively.

He is the recipient of the Andlinger Center's 2023-24 Maeder Graduate Fellowship, which is supported by the Paul A. Maeder '75 Fund for Innovation in Energy and the Environment.

Evelyn Navarro Salazar
Ph.D. Candidate
Chemical and Biological Engineering
Adviser: Celeste Nelson, Wilke Family Professor in Bioengineering



Evelyn Navarro Salazar. Photo by Corban Swain

Salazar's research focuses on lung development — specifically the alveoli, the air sacs that enable the exchange of oxygen and carbon dioxide. She aims to observe the dynamic series of signals that lead progenitor cells to differentiate into the two types of cells that form the outer layer of these air sacs.

"If we can understand the dynamics of how this happens, we can replicate it with optogenetics and then hopefully create an in vitro model that better represents what's happening physiologically," she said, referring to the technique of using light to control the activity of genes. "This is very important for studying diseases or development of the alveoli."

In May, Salazar was among the recipients of an annual Teaching Award from Princeton's Graduate School for her work as a preceptor in "Mass, Momentum, and Energy Transport." Celeste Nelson, the course's instructor and Salazar's Ph.D. adviser, said Salazar "had an amazing rapport with the students" and is "an incredibly talented and compassionate teacher."

Students were grateful to Salazar for going "above and beyond in ensuring that we as students have all the resources to succeed and to love the subject. It is obvious that she has a deep appreciation and passion for the work she is doing."

ALUMNI LEADERSHIP IN ACADEMIA AND INDUSTRY

Drinda Benjamin '97 has joined Glucotrack, a medical device company focused on glucose monitoring, as vice president of marketing. Her experience in marketing and health technology includes positions at Intuity Medical, where she developed and executed commercial strategies for an integrated blood glucose monitoring system. Benjamin's B.S.E. in civil engineering is from Princeton and her M.B.A. is from Georgetown University.


Thomas Doran

Thomas Doran '87 is now president of Highmark Health Plan, the nation's fourth-largest Blue Cross Blue Shield affiliate. Doran joined Highmark in 2017 as president of the company's stop-loss subsidiary HM Insurance Group, and previously served as COO. Doran holds a B.S.E. in mechanical and aerospace engineering from Princeton.

Hafize Gaye Erkan *06 was named the first female governor of the Central Bank of the Republic of Turkey. Previously, she was at First Republic Bank, where she was chief investment officer and co-risk officer and later moved to co-CEO and president. Earlier in her career she held leadership positions at Goldman Sachs. Erkan graduated from Princeton with a Ph.D. in operations research and financial engineering.


Samara Firebaugh

Samara Firebaugh '95 is the new academic dean and provost of the U.S. Naval Academy. She began her career there in 2001 as an assistant professor of electrical and computer engineering. Since then she has held other faculty and leadership positions, including associate provost for academic affairs. Firebaugh received a B.S.E. from Princeton and a Ph.D. from MIT, both in electrical engineering.


Alec Gallimore

Alec Gallimore *92 is the new provost and chief academic officer at Duke University. He moved from the University of Michigan, where he was the Robert J. Vlasic Dean of the College of Engineering since 2016. Gallimore received a Ph.D. in mechanical and aerospace engineering from Princeton; his undergraduate degree is from Rensselaer Polytechnic Institute.

Through the ROTC program at Princeton in 1998 and as a mechanical and aerospace engineering major, Colonel **Carlos Gorbea** '98 commissioned into the Army Corps of Engineers, and has served in the military in numerous ways. He recently returned home to Puerto Rico to become the commander of the 1st U.S. Army Reserve Mission Support Command of Puerto Rico and the Virgin Islands. Earlier in his career, he worked for BMW on the development of hybrid and electric vehicles. Gorbea holds a B.S.E. from Princeton, an M.B.A. from MIT, and a doctorate from the Munich Institute of Technology.


Carlos Gorbea

A former executive at Meta's Oculus, Microsoft's Xbox, and Discord, among other leadership positions in the tech field, **Elizabeth Hamren** '93 was named CEO of Amazon's Ring, the smart doorbell and home security technology company. She will also lead Amazon's Blink, Key, and Sidewalk. Hamren earned a B.S.E. in civil engineering and operations research from Princeton, followed by an M.B.A. from Harvard.

Nogin, a provider of innovative ecommerce technology, appointed **Jonathan Huberman** '88 as president, chief executive, and chairman of the board. He was previously the president and co-CEO. Huberman joined Nogin's executive team in 2022 after serving as chairman and CEO of Software Acquisition Group Inc. III. He earned an A.B. in electrical engineering and computer science from Princeton and an M.B.A. from The Wharton School.

Photos courtesy of the subjects

Andrew Krivoshik '90 was appointed chief medical officer at Frontier Medicines Corporation, a precision medicine company working to advance transformational therapies against otherwise undruggable disease-causing targets. Krivoshik, who has over 20 years of experience in drug development, holds a B.S.E. in electrical engineering from Princeton, an M.D. from the University of Illinois College of Medicine at Urbana-Champaign, and a Ph.D. in biophysics and computational biology from the University of Illinois at Urbana-Champaign.


Stephen Markle

Stephen Markle '96 was appointed COO of Itemize, an AI-powered intelligent automation platform for B2B commerce. Markle was formerly president and CEO of BirchStreet Systems, and before that was vice president of solutions management at SAP Ariba. His B.S.E. from Princeton is in mechanical and aerospace engineering.


Katy Milkman

Katy Milkman '04, the James G. Dean Endowed Professor and professor of operations, information, and decisions at The Wharton School, published "How to Change: The Science of Getting From Where You Are to Where You Want to Be." Milkman, who holds a B.S.E. in operations research and financial engineering from Princeton and a Ph.D. from Harvard Business School, is also the co-founder of the Behavior Change for Good Initiative at Wharton.

Eric Pierce Young '98 was appointed CEO of VeriDaaS Corporation, a provider of commercially available Geiger-mode LiDAR data. Young, who holds a B.S.E. from Princeton in mechanical and aerospace engineering and an M.B.A. from Dartmouth College, previously served as the senior vice president of operations at Ever-Commerce Solutions, a technology platform providing integrated SaaS solutions.

ALUMNI HONORS FOR RESEARCH AND INNOVATION

Claire Adjiman *98, a professor of chemical engineering at Imperial College London, was elected to the U.S. National Academy of Engineering as an international member. She was elected for developing the fundamental principles for advanced thermodynamic modeling of complex fluids and for improving industrial productivity using those models. Along with a master of research degree in molecular engineering from Imperial, Adjiman earned a Ph.D. in chemical engineering from Princeton.

A winner of the Nobel Prize in Chemistry, **Frances Arnold** '79 received an honorary degree from Oxford University in June. As the Linus Pauling Professor of Chemical Engineering, Bioengineering, and Biochemistry and director of the Donna and Benjamin M. Rosen Bioengineering Center at the California Institute of Technology, she was recognized for her pioneering work in directed evolution. Arnold graduated from Princeton with a B.S.E. in mechanical and aerospace engineering and received a Ph.D. in chemistry from the University of California-Berkeley.

Cato Laurencin '80 received the Shu Chien Achievement Award at the Biomedical Engineering Society Cellular and Molecular Bioengineering conference. He was recognized for his contributions to the cellular and molecular bioengineering field and for founding the field of regenerative engineering. Laurencin, the University Professor and Albert and Wilda Van Dusen Distinguished Endowed Professor of Orthopaedic Surgery at the University of Connecticut, received a B.S.E. in chemical engineering from Princeton, a Ph.D. from MIT, and an M.D. from Harvard.


Claire Adjiman


Frances Arnold

Photos courtesy of the subjects