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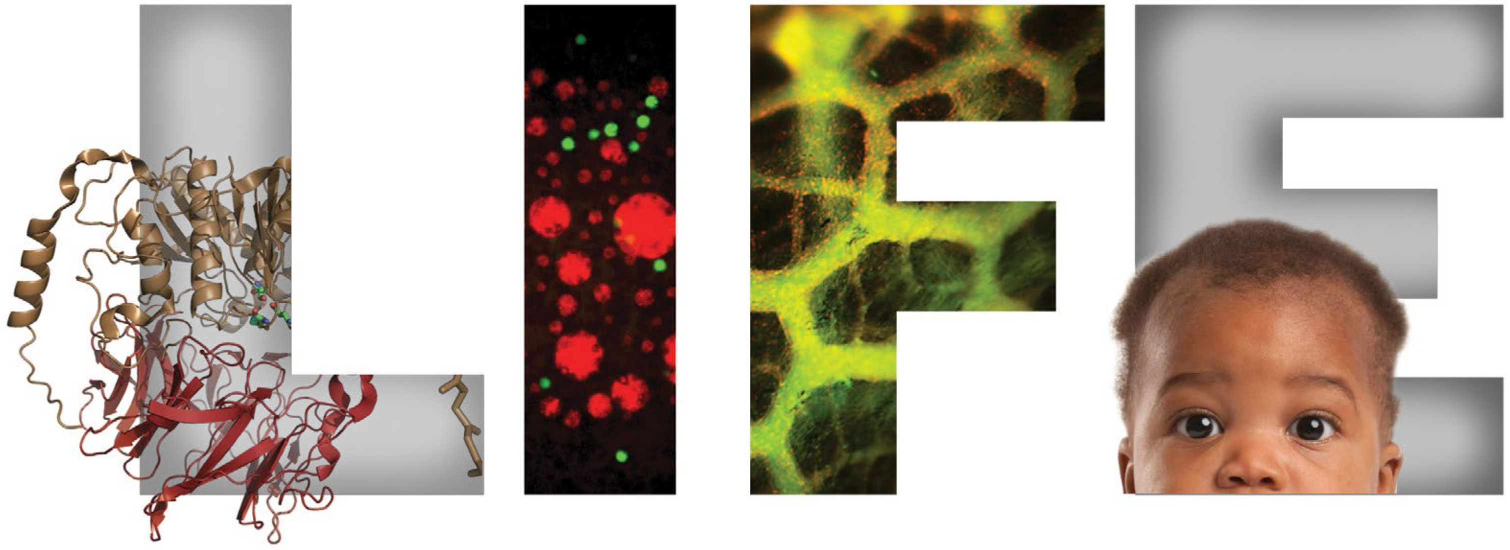
EQuad News

Summer 2014
Volume 26, Number 1



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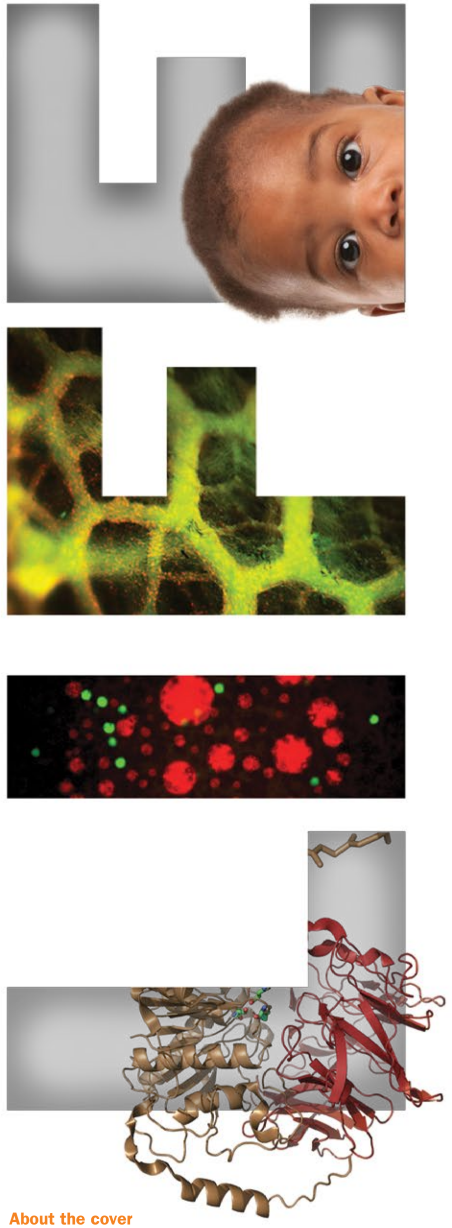

About the cover
The scientific images represent a range of work from molecules to whole organisms: in the L, a model of an enzyme studied in the lab of A. James Link BSE '00; in the I, nucleoli from egg cells of the African clawed frog from the lab of Cliff Brangwynne; in the F, bearded dragon embryo lung tissue from the lab of Celeste Nelson (exhibited in "Art of Science" 2011).

E DEAN'S NOTE

Engineering and biology: A vital connection

What is it that makes crossing borders between academic fields so appealing? The way Eric Wieschaus, Princeton biologist and Nobel laureate, describes it on page 9 of this magazine, emerging outposts of research and teaching that span multiple fields are like cities that arise at the border of two countries. The sometimes chaotic mix of cultures and ideas creates a nexus of creativity and progress. The rich opportunities, in turn, attract more people who might not even be from the originating areas.

So it is with engineering and biology. The articles in this magazine describe work that can be hard to classify. In some cases engineers are using their expertise in complex systems or mechanics to make fundamental discoveries about growth and structure in living organisms; in others, engineers are creating tools that will bring needed advances for human health. The bottom line is that it exemplifies what I see as the best in engineering: bringing together whatever expertise is needed to solve a problem, whether a fundamental question of science or an immediate societal need.

I want to take a moment here to highlight and congratulate our 2014 valedictorian, Katherine Pogrebniak (the second BSE student in a row to receive this honor). Her research fits perfectly the theme of this magazine, combining the tools of computer science and "big data" to bring fresh insight to medicine and biology.

The collaborative spirit of engineering includes you – alumni, colleagues and friends. Please stay in touch and let's find ways to work together.

H. Vincent Poor Ph.D. '77
Dean
Michael Henry Strater University Professor of Electrical Engineering

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Photo by Danielle Alio

MIGHTY MATH: VALEDICTORIAN POGREBNIAK ADVANCES MEDICINE THROUGH COMPUTATION

Katherine Pogrebniak (left), worked with Mona Singh (right), a professor of computer science and the Lewis-Sigler Institute for Integrative Genomics, on a computational method for evaluating how certain substances bind with proteins, a fundamental question of modern biology. "I started with math," said Pogrebniak, "but I have always been interested in biomedical problems because I was excited about their real-world applications."

By her own account, when Katherine Pogrebniak first arrived at the National Eye Institute in the summer before her sophomore year at Princeton, she knew relatively little about the highly complex research in the national laboratory.

By the end of the summer, she had sketched out the framework of a model to analyze a protein that researchers believe could be a critical factor in the development of an eye disease that affects children.

"She has this tremendous ability to learn," said Yuri Sergeev, a senior researcher at the Bethesda, Maryland, institute, which is a branch of the National Institutes of Health (NIH). He said Pogrebniak brought an intense focus to her work, first learning biological aspects of the project and then bringing her computational skills to bear on working out a solution.

Pogrebniak's peers and professors speak of the intellect and determination that have led her to the top of her class. A computer science major from Jacksonville, Florida, she is the valedictorian of the Princeton Class of 2014, and delivered an address at the University's Commencement ceremony on June 3.

"She is very intelligent and she also has a superb work ethic," said Mona Singh, a professor of computer science and the Lewis-Sigler Institute for Integrative Genomics. Singh, who advised Pogrebniak for her independent project, said her contribution to her lab was akin to that from an advanced graduate student.

In a second internship at the NIH last summer, Pogrebniak helped a team of researchers develop a new method of using magnetic resonance imaging (MRI) in the treatment of patients with multiple sclerosis (MS). Daniel Reich, a principal investigator at NIH and the team leader, called Pogrebniak "an outstanding young star," and said that through her work the lab was able to achieve a major goal in imaging research.

In May, the results of Pogrebniak's work at the NIH were presented at the annual meeting of the International Society for Magnetic Resonance in Medicine in Milan.

"Katherine made quite an impression on me and all my colleagues," Reich said in a letter to the University. He noted that in applying computation to solve biological problems, "none of us has any doubt that Katherine will become a world leader." ▶

MIGHTY MATH: VALEDICTORIAN POGREBNIAK ADVANCES MEDICINE THROUGH COMPUTATION

(continued from page 1)

Understanding the big picture

Pogrebniak is the first woman earning a Bachelor of Science in Engineering at Princeton to be named valedictorian. She also received a certificate in engineering biology.

For her independent research, Pogrebniak joined a group in Singh's lab, which is studying how proteins bind with other molecules, called ligands. These binding interactions are a fundamental process and understanding them could lead to new drugs and medical therapies.

Pogrebniak assisted the effort by finding ways to find repeated measurements in massive data sets that could skew an analysis by suggesting that certain interactions are more common than they really are.

"I was very impressed with Katherine's degree of scientific maturity in dealing with the problems and coming up with alternatives," said Dario Ghersi, a postdoctoral researcher who worked with her on the project. "We tried many things to reduce the redundancy in this data set. Her persistence was key."

Photo by Denise Applewhite

Computation and health

Colleagues uniformly speak of Pogrebniak's consideration for fellow students and coworkers. She has served for two years as a residential college adviser at Wilson College; Eduardo Cadava, an English professor and the college master, spoke of her "wild intelligence – which she wears with grace and humility."

Pogrebniak said she has long wanted to work in medicine.

"I started with math," Pogrebniak said. "But I have always been interested in biomedical problems because I was excited about their real-world applications."

Pogrebniak will attend the University of Cambridge as a Churchill Scholar in the fall and plans to obtain a master's degree in computational biology. After that, she intends to pursue a medical degree and a doctorate at Stanford University.

The summer before her senior year at the NIH's National Institute of Neurological Disorders and Stroke, she assisted with ways to formulate treatments for people with MS. Reich, the lead researcher, said in his letter to Princeton that Pogrebniak came up with a method to use errors in scan data to identify lesions in the cortex – "a major but hitherto unachieved goal of contemporary MS-imaging research."

"In imaging, there is a lot of physics and math, but most of the people who do imaging can't deal with massive amounts of data," he said. "Katherine is certainly someone who can do that." **–John Sullivan**

Pogrebniak, a computer science major from Jacksonville, Florida, gives the valedictory oration, telling her peers that it is their time to "venture into the unknown and create a new path."

MODERN EXPERTISE BUILDS BRIDGE TO ANCIENT MARVEL

Many engineering lectures concern themselves with cutting-edge technology but at a recent talk on bridge construction, Princeton professor Branko Glišić asked his audience to go back nearly 2,000 years.

"You have to think like a Roman," Glišić told students and faculty gathered for a brown-bag lunch. He gestured to a schematic diagram of an arch on the screen behind him. "You minimize connections because they add complication."

Glišić, an assistant professor of civil and environmental engineering, was speaking about Trajan's Bridge, a wood-and-masonry structure that the Romans constructed between 103 and 105 A.D. to span the Danube River between what is now Serbia and Romania. At more than a kilometer long (six-tenths of a mile), it is considered a wonder of the ancient world, but nearly all details of its form and construction have been lost. Glišić and former undergraduate Anjali Mehrotra have reconstructed the engineering behind the bridge and published their findings in the Journal of Cultural Heritage.

Glišić and Mehrotra used modern engineering analysis, coupled with a review of available materials and historic records of Roman construction techniques, to draw their conclusions, some of which run counter to historical assumptions. Mehrotra majored in civil and environmental engineering and graduated in 2013.

Built under the Emperor Trajan, the bridge has inspired wonder for centuries.

"Brilliant, indeed, as are his other achievements, yet this surpasses them," wrote Cassius Dio, the Roman consul and historian.

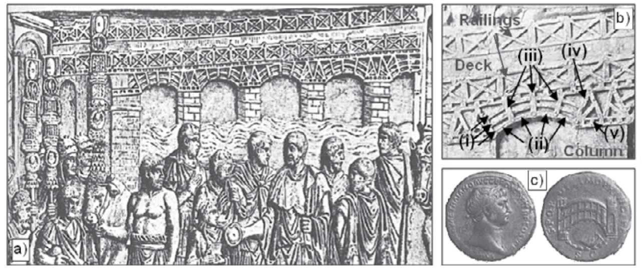
The researchers reviewed historic representations of the bridge that were proposed by scientists over the past two centuries, but rejected all or elements of various analyses either because of instability issues or the use of techniques that the Romans were unlikely to have mastered, such as fixed joints.

Examinations of the remaining masonry piers at the site, carried out in 1979 by Serbian archaeologists Milutin Garašanin and Miloje Vasić, showed that the Romans drove support beams into the piers to strengthen the arches.

"The holes gave us the most probable positions for the ends of the arches," he said. The support beams also would have given sufficient stability to the bridge.

Glišić said without a definitive historical record, there is no way to be sure how the bridge looked. But he said that applying engineering analyses can narrow the possibilities.

"We cannot say it really was like this," he said, "but we can say it very likely was like this." **–JS**



A carving from Trajan's Column in Rome (at left and upper right) and a contemporary Roman coin provided clues to the bridge's form. (Images courtesy of Branko Glišić)

Photo by Frank Wojciechowski

Researchers led by Branko Glišić, an assistant professor of civil and environmental engineering at Princeton, used modern engineering analysis to determine the materials and techniques that ancient Roman engineers used to build Trajan's Bridge over the Danube River.

A FAREWELL TO ARMS? NOVEL TECHNIQUE COULD FACILITATE NUCLEAR DISARMAMENT

Photo by Elle Starkman

Assistant Professor Alex Glaser displays a device known as the "British Test Object," which simulates the materials used in a nuclear warhead and is used for testing methods of verifying the authenticity of the weapons.

A key step in nuclear disarmament requires solving a conundrum: how to verify that a weapon slated for destruction contains a true warhead, yet not reveal any information whatsoever about the device. Using a concept borrowed from computer science – a so-called "zero-knowledge proof" – a Princeton engineer has collaborated with scientists at the Princeton Plasma Physics Laboratory (PPPL) to invent such a system.

The researchers published their approach in the June 26 issue of the journal Nature.

The secrecy is required to avoid revealing classified details about materials or design that must remain off-limits to inspectors, the authors said. Most disarmament efforts so far have relied on counting missile silos, submarines or other deployment vehicles that are easily identified. Future rounds, however, will place limits on tactical or non-deployed weapons, which must be identified and counted individually.

"What we really want to do is count warheads," said Alex Glaser, an assistant professor of mechanical and aerospace engineering and international affairs and an author of the Nature paper.

Glaser co-wrote the article with Robert Goldston Ph.D. '77, a physicist at PPPL, and Boaz Barak, a computer scientist formerly at Princeton and now at Microsoft Research. PPPL is a U.S. Department of Energy national lab administered by Princeton University.

Their system would compare a warhead to be inspected with a known true warhead to see if the weapons matched. This would be done by beaming high-energy neutrons into each warhead and recording how many neutrons passed through to detectors positioned on the other side. Neutrons that passed through would be added to those already "preloaded" into the detectors by the warheads' owner – and if the total number of neutrons were the same for each warhead, the weapons would be found to match. But different totals would show that the putative warhead was really a spoof. Prior to the test, the inspector would decide which preloaded detector would go with which warhead.

Glaser hit upon the idea over a lunch hosted by David Dobkin, a computer scientist who was dean of the Princeton faculty at the time. Glaser described the inspectors' dilemma and Dobkin immediately recognized it as a problem requiring a zero-knowledge proof, which are widely used in applications such as verifying online passwords. Glaser then turned to Barak, an expert in such proofs, and to Goldston, whose work at PPPL involves powerful neutron sources that could simulate a nuclear device.

A project to test the researchers' approach is now under construction at PPPL.

The project was launched with a seed grant from the Simons Foundation of Vancouver, Canada, that came to Princeton through Global Zero, a nonprofit organization. Support was also provided by the U.S. Department of State, the Department of Energy and, most recently, a $3.5 million grant from the National Nuclear Security Administration. **–John Greenwald**

HACKPRINCETON DRAWS 500 STUDENTS TO BRAINSTORM AND BUILD

A robotic insect that waves hello, a calculator controlled by a few pokes in midair, an alarm clock that sprays water and posts embarrassing social media statuses — not ordinary products of a college student's weekend. But this was no ordinary weekend — it was HackPrinceton.

For 36 hours culminating March 30, Princeton's Jadwin Gym was packed with roughly 500 undergraduates from more than 40 universities working furiously on programming and hardware projects. Such "hackathons" have grown in popularity in recent years providing students with food, camaraderie and a location to devote a weekend to developing ideas for products or services.

HackPrinceton received support from the Stephen C. Johnson '64 Slingshot Fund for Innovation, which was established by the Johnson family to foster innovation, including entrepreneurial ventures, among undergraduates.

The Princeton event was organized by electrical engineering major Adam Yabroudi and Hansen Qian, a computer science major. A panel of experienced technologists in business and academia judged the best projects, which were awarded prize money and "swag" from sponsors such as Google and Facebook.

The students came from all around the East Coast and beyond. Yi Qin and Jian Zhang of Purdue University drove 13 hours, picking up teammate Paul Wong from the University of Pittsburgh. The three developed SmartCar, an inexpensive accident-avoidance system for older cars that combines turn-by-turn navigation with tools that issue a warning if a driver leaves a lane or risks a collision.

"We just really wanted to build something cool," Qin said. **–Stacey Huang '15**

Photo by Frank Wojciechowski

HackPrinceton, a weekend-long event held in Jadwin Gym March 28-30, brought roughly 500 college students to campus to build hardware and software tools and toys. The event was organized by Princeton undergraduates Hansen Qian (left) and Adam Yabroudi (right) with a committee of student volunteers.

TATTOO REMOVAL TO CRUDE OIL EXTRACTION: RESEARCH WITH COMMERCIAL APPEAL

Graduate student George Khoury said he must have practiced a hundred times prior to taking the stage at this year's Innovation Forum at Princeton.

"I've never done anything like this before," said Khoury, whose group took home the $10,000 second prize with a method of discovering HIV inhibitors. "It was a once-in-a-lifetime opportunity."

Khoury's group – led by Christodoulos Floudas, the Stephen C. Macaleer '63 Professor in Engineering and Applied Science, and including fellow graduate student James Smadbeck – was one of 10 teams that pitched the commercial potential of research ranging from advances in medicine to painless tattoo removal.

The ninth annual event, sponsored by Princeton's Keller Center, took place on Feb. 26 before an audience of nearly 200 people in the University's Fields Center. A member of each team delivered a three-minute pitch to a panel of judges consisting of investors and business leaders. After each presentation, the judges were allotted five minutes to ask questions on details such as potential risks and competitors and how they would use the funding.

The first prize, of $15,000 in funding, was won by a team that developed a technology for mass production of "Janus particles," tiny spheres with two distinct sides composed of typically incompatible materials such as plastics and metals. Vikram Pansare, a Ph.D. student, presented the idea for a team including Professors Robert Prud'homme and Rodney Priestley and graduate students Chris Sosa and Chuan Zhang. Pansare said the program honed his business, as well as his technical, skills.

"You're not just working with one thing," he said. "Dealing with both simultaneously, you learn so much." **–Catherine Shen**

Photo by Frank Wojciechowski

The panel of judges for the Innovation Forum is made up of investors and business leaders.

Photos by Denise Applewhite

The Andlinger construction site gives students the opportunity to take a close look at how materials and engineering help shape the emerging structure.

EVEN UNDER CONSTRUCTION, ANDLINGER LAB TEACHES

The class walked into a cavernous construction site that is becoming the Andlinger Center for Energy and the Environment at Princeton University. Light, filtering from the open floors above, lined the gray concrete floors and the steel beams that cross the high ceiling. Construction crews had knocked off a few minutes earlier. Sound in the space, far below street level, was muted.

Sam Rozycki, leading the small group of students, pointed to open spaces cut from the middle of a nearby beam.

"A lot of that beam is missing," said Rozycki, senior project manager at the University's Office of Design and Construction. "Can anyone tell me why it still works?"

Dennis Smith, a sophomore majoring in civil and environmental engineering, spoke up, "Most of the strength for resisting bending is in the flanges."

Rozycki agreed.

"The engineer is more concerned about bending in the center of the beam, which is addressed by the flanges," he said. "Shear strength is more of a concern at the end of the beam."

Leading student groups through construction sites is not typically part of a construction manager's job, but the Andlinger project on Olden Street offers student engineers an opportunity for firsthand observation of the fundamentals they are learning in class. On one recent tour, Claire White, an assistant professor of civil and environmental engineering and the Andlinger Center for Energy and the Environment, used the site to demonstrate to the students in her class "Materials in Engineering" how concrete and steel were used in various ways to shape the emerging structure.

"The week before, we were in a cement plant," said White. "It is very important to give the students real-world experience."

The new building, scheduled to open in summer 2015, will hold lecture and laboratory classrooms, office space, a lecture hall, conference rooms, and research labs, including "clean rooms" that have ultra-low dust levels and labs that house some of the world's most sophisticated imaging and analytical equipment.

Emily Carter, the Gerhard R. Andlinger Professor in Energy and the Environment and founding director of the center, stressed the importance of "the Andlinger Center as a living laboratory, both as it is being built and upon occupancy."

Added Carter, "Students will have the opportunity to not only witness and learn about the creation and operation of this building dedicated to sustainability but also to participate in cutting-edge research aimed at preserving the planet for future generations."

Rozycki, who estimates that he has given about 18 class tours of the site since construction began, said he is continually impressed by the questions he receives from students.

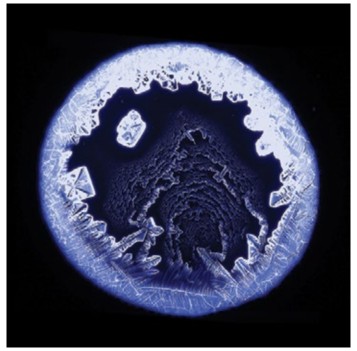
Richard Garlock, a visiting lecturer in civil and environmental engineering, has brought several of his classes to the site. In fact, the window of his classroom, in the Engineering Quadrangle, overlooks the project, and he tries to end every class with a look through the window at progress on the construction site.

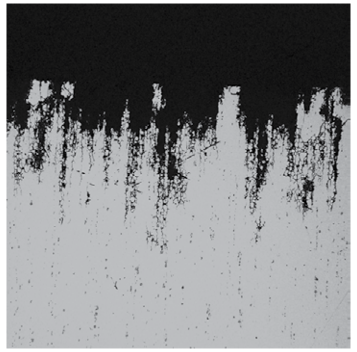
Garlock, an associate partner with the New York-based firm Leslie E. Robertson Associates and the project manager for the new 4 World Trade Center Tower project, said it is important for engineering students to get into the field during their studies.

"You have to set their sense of scale and you can't do it in the classroom alone," he said. "They have to see and smell the materials and the space – you have to get their eyes used to seeing what is going on."

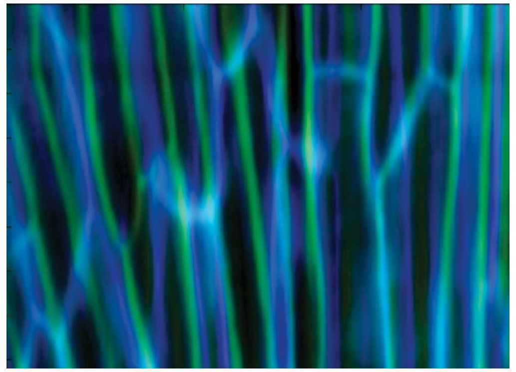
Garlock usually takes his students on tours of several sites during a term. He said one of the benefits of touring Princeton projects is that Rozycki and his colleagues at the Office of Design and Construction go out of their way to be helpful. **–JS**

Students study a model of the Andlinger Center, scheduled to open in summer 2015. Emily Carter, the Gerhard R. Andlinger Professor in Energy and the Environment and founding director of the center, described it as a "living laboratory, both as it is being built and upon occupancy."





Images from Princeton University's 2014 "Art of Science" exhibit, clockwise from lower left: "#5" by Nathan Tyrell BSE '14 (Mechanical and Aerospace Engineering); "Vitamin C" by Nathan Myhrvold Ph.D. '83 (Applied Mathematics); "Cave of Crystals" by Hyoungsoo Kim, François Boulogne and Howard Stone (MAE); "Ring of Fire" by Clara O'Farrell BSE '08 (MAE); "Watermarks" by Sara Sadri (Civil and Environmental Engineering); and "Elodea leaf cell" by Nicolas Pegard and Jason Fleischer (Electrical Engineering).



'ART OF SCIENCE' EXHIBIT SPANS ENGINEERING AND NATURAL SCIENCES

The 2014 "Art of Science" exhibit, featuring 44 images and 12 videos created during the course of scientific research, opened May 8 at Princeton University's Friend Center. An online gallery of the current and past "Art of Science" exhibits can be viewed at **http://artofsci.princeton.edu.**

More than 200 people attended the opening reception at which the top awards in a juried competition were announced and visitors voted on People's Choice awards. The images and videos exhibited were selected for their artistic merit from more than 300 submissions from undergraduates, graduate students, postdocs, staff and alumni representing more than 25 departments.

"So much of science and engineering involves video or animation these days that it was inevitable we would include it in 'Art of Science,'" said Dan Quinn, a graduate student in mechanical and aerospace engineering who is one of the 2014 exhibit organizers.

The winning print entries chosen by the panel of judges were: first place went to "Watermarks" by Sara Sadri, postdoctoral researcher, civil and environmental engineering; second place for "Fungus among us" by James Waters, postdoctoral researcher, ecology and evolutionary biology; and third place went to "Portrait of the artist in the air shower" by Yasmin Afsar, a graduate student in electrical engineering.

The top video award went to Sabine Petry, assistant professor of molecular biology, for her video "Microtubules branch out."

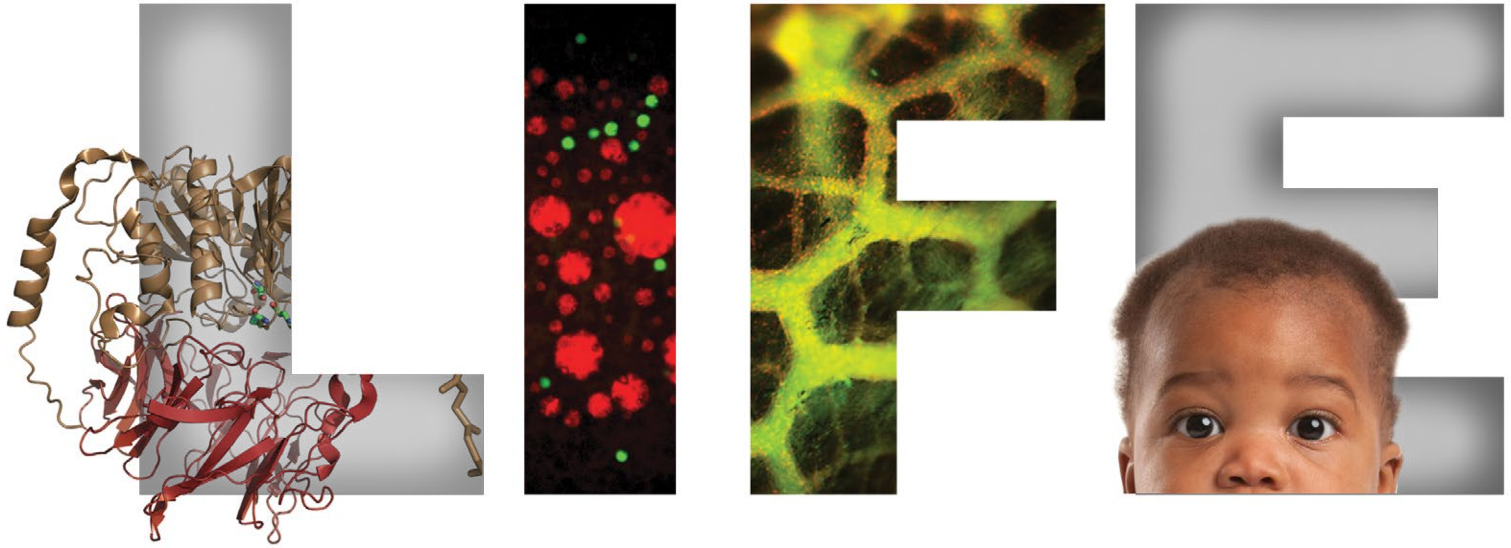
People's choice

Of 185 ballots cast for People's Choice, first place for still images went to "Fruit fly factory" by graduate students Yogesh Goyal and Bomyi Lim, postdoctoral researcher Miriam Osterfield and Stasnislav Shvartsman, a professor of chemical and biological engineering and the Lewis-Sigler Institute for Integrative Genomics. The People's Choice award for video went to "Plenty of fish" by graduate student Colin Twomey and postdoctoral researcher Haishan Wu of ecology and evolutionary biology.

Zach Donnell, a graduate student in molecular biology and one of the 2014 organizers, noted that, as in past years, the winners selected by the jury and those selected by visitors to the opening reception were completely different. "It reminds us that art is quite a subjective thing," he said.

The exhibit at the Friend Center is free and open to the public through April 2015.

–Teresa Riordan



PIZZA at the BORDER: 'NOVEL INTERACTIONS' SPUR BIOLOGICAL DISCOVERY

by John Sullivan

Eric Wieschaus had a question.

It was Friday afternoon, and Stephanie Weber was well into her presentation on cellular structure when Wieschaus, a molecular biologist and Nobel laureate, politely raised his hand and gave the talk a nudge in a different direction.

"We'd been thinking about the problem from a physics perspective," said Weber, a post-doctoral researcher in chemical and biological engineering. "Eric's question was about the biology – about transcriptional regulation."

For a few minutes, the question bounced back and forth among the group gathered in a large conference room in Hoyt Laboratory. Grad students, postdocs, junior and senior professors ran with the new thought for a while until Weber resumed her talk. After, Weber and Wieschaus arranged to talk further about the approach.

"Science is essentially social," Wieschaus, the Squibb Professor in Molecular Biology, said later. "Somehow you have to think of a way for people who are truly scientists – whether they are grad students, postdocs or professors – to participate. How do you do that? One way is to serve pizza."

Photo by Denise Applewhite

Faculty members, graduate students and postdoctoral researchers from across the University gather every Friday to discuss current research at the intersection of biology and engineering. Participants say they value the exchange of perspectives in these informal sessions.

In what has become a Friday afternoon tradition, the bioengineering faculty orders pizza and offers a rolling series of lectures on ongoing research. Whether the participants are, like Weber, postdocs making their first formal presentation or senior scientists like Wieschaus, the atmosphere is democratic. It is also eclectic; the gatherings frequently include representatives from a wide range of scientific disciplines.

That makes sense; bioengineering is a hybrid by its very nature. Wieschaus calls the field a scientific "border city." It is a deliberate

‘NOVEL INTERACTIONS’ SPUR BIOLOGICAL DISCOVERY *(continued from page 9)*

merger of two well-settled scientific disciplines and, as a result, attracts people who are comfortable working outside their normal framework.

“It is not just the confrontation of the border,” he said. “Immigrants from all over the world are attracted to border cities. People who are in other areas see it as a place where novel interactions and ideas can occur.”

Bonnie Bassler, the Squibb Professor in Molecular Biology and chair of the Department of Molecular Biology, said Princeton has long had the philosophy that the borders of academic disciplines should not become an obstacle to scientific inquiry. In fact, today’s students are not only comfortable working across different fields, they expect it.

“Students come here expecting open mindedness,” she said. “Someone might be trained in engineering but they want to immerse themselves in biology.”

Richard Register, the Eugene Higgins Professor of Chemical and Biological Engineering and the department chair, said that bioengineering at Princeton “tends to focus on the fundamental, rather than the clinical, level.”

“A particular strength that we have, and that makes Princeton distinctive, is that we have a very strong life sciences presence at the University, and a strong commitment to biological engineering within the engineering school,” he said. In his department alone, Register added, “We have very high-quality people from a range of backgrounds but all of whom fit within chemical and biological engineering.”

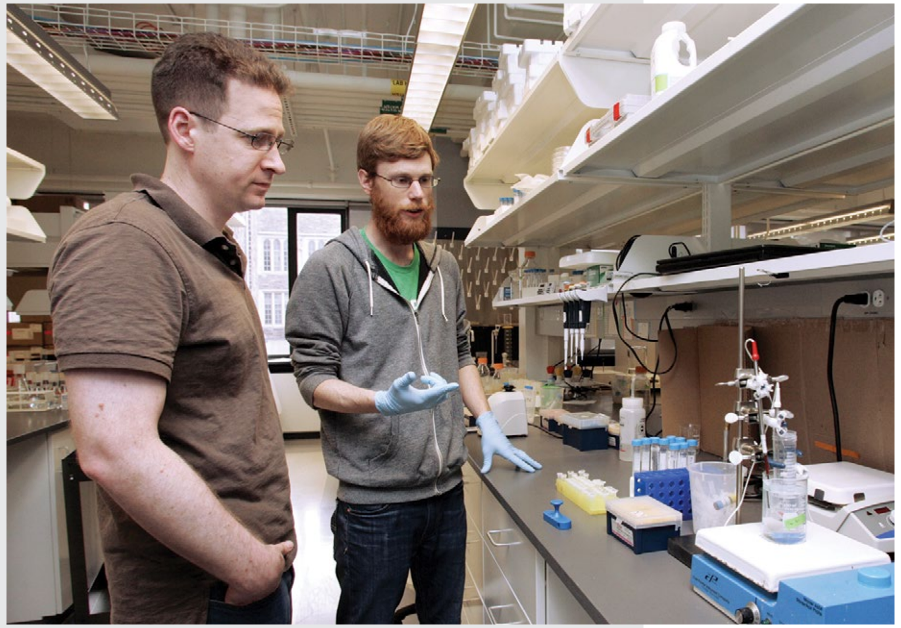
The diversity of backgrounds, and the commonality of interest, is valued by the participants. In many ways, the research focus is represented by the Friday afternoon pizza.

“It’s a formal presentation but at the same time it’s a discussion among colleagues,” Weber said. **E**

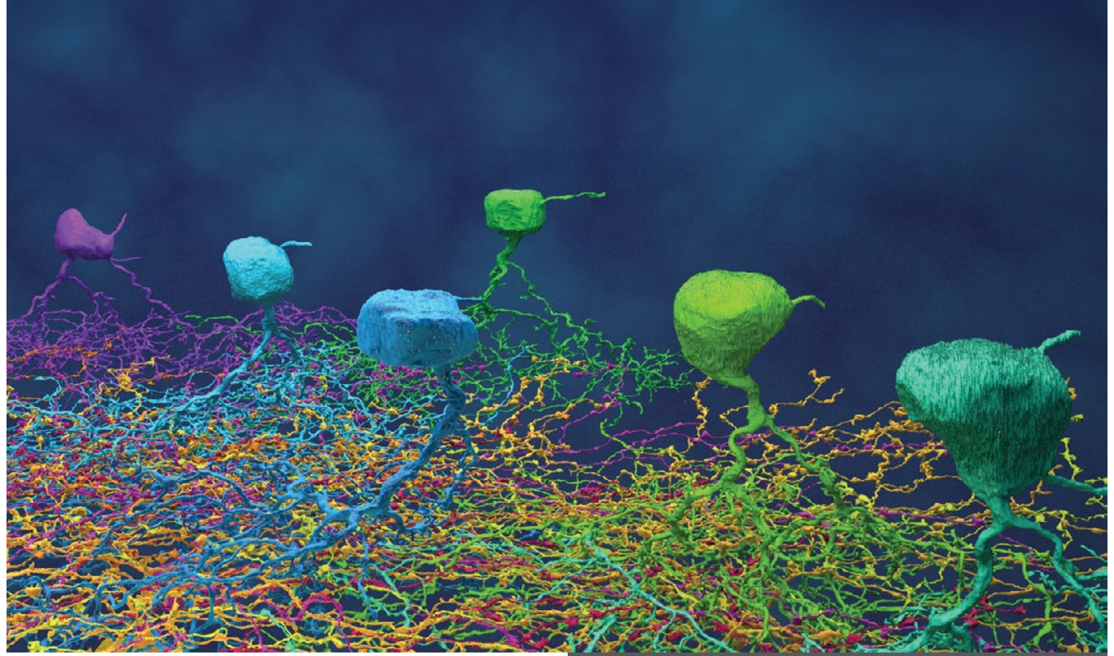
BACK TO BASICS

Modern medicine, from cardiac surgery to chemotherapy, rests on a foundation of reliable antibiotics. But health authorities around the world warn that the effectiveness of antibiotics is under increasing threat from resistant bacteria. Mark Brynildsen, an assistant professor of chemical and biological engineering, is seeking solutions to this problem through new ways to combat dangerous bacteria. Researchers in his lab are combining several approaches: disrupting bacteria’s ability to infect people; unravelling bacteria’s ability to survive anti-biotics and other forms of stress; and preventing formations called biofilms, which some bacteria use to protect themselves from outside threats such as antibiotics. The lab is also pursuing fundamental research into the interaction between bacteria and their hosts. “Antibiotics work anywhere they come in contact with bacteria, which means pressure to develop resistance occurs both within sick people and outside in the environment,” Brynildsen said. “To prevent illness, we only need agents that are effective against infections in the host, which is a more targeted approach with a potentially longer time of effective use than conventional antibiotics.” **–JS**

Photo by Frank Wojciechowski



Assistant Professor Mark Brynildsen (left) talks with graduate student Jonathan Robinson.



In Eyewire, an online game, science enthusiasts around the world interact with computer-generated feedback to map the convoluted paths of neurons, depicted above, through the retina.

EYEWIRE:

A game helps map the brain

In a much-cited talk at a 2010 TED conference, Sebastian Seung introduced the proposition, “I am my connectome.”

Seung, a computational neuroscientist then at MIT, suggested that what makes a person unique is more than their collection of genes, or genome. Rather it is their connectome, the connections between all their neurons, that arises from genetics but is shaped by experience.

“The connectome is where nature meets nurture,” Seung said.

Seung joined the Princeton faculty in January, jointly appointed in the Department of Computer Science and the Princeton Neuroscience Institute. With him, he brings his ambitious plan to map the human connectome, which includes a popular online game he created to enlist people from around the world in tracing the interwoven tangle of neurons in the retina of the eye.

“We need an army of people to go out and explore that jungle,” Seung told NPR’s “Morning Edition” in May. “What could be more exciting than exploring the brain? Much more exciting than any artificial video game.”

Called Eyewire, the game has engaged 120,000 people from 140 countries. Their online “play” already has contributed to a paper published in May in the journal Nature suggesting how the perception of motion arises from the structure of neuronal connections in the retina.

At Princeton, Seung plans to collaborate with neuroscientists who have developed sophisticated methods of recording neural activity associated with behavior and decision-making in animals. “The retina is a great way to understand perception,” Seung said. “We want to move beyond perception to cognition and learning and memory.” **–Steve Schultz**

LASER REVEALS *health clues in* HUMAN BREATH

High levels of the molecule nitric oxide can alert doctors to inflammation in critical areas of the body such as the cardiovascular system. In a short video, Gerard Wysocki, an assistant professor of electrical engineering at Princeton, explains how his lab is developing a single system that measures levels of nitric oxide isotopes in breath, as well as nitrites and nitrates in blood and urine. Wysocki’s device uses a magnetic field and a high-frequency modulated laser to detect levels of nitric oxide isotopes as low as one part per billion in samples from patients. The measurement takes only one second. “The analyzer has to be very sensitive to look at such a minute amount of nitric oxide so quickly,” he said. “That is the main difficulty in measuring important reactive species such as nitric oxide.” **http://bit.ly/WysockiVideo**

SHAPING UP: DISCOVERING HOW ORGANS FORM

by John Sullivan

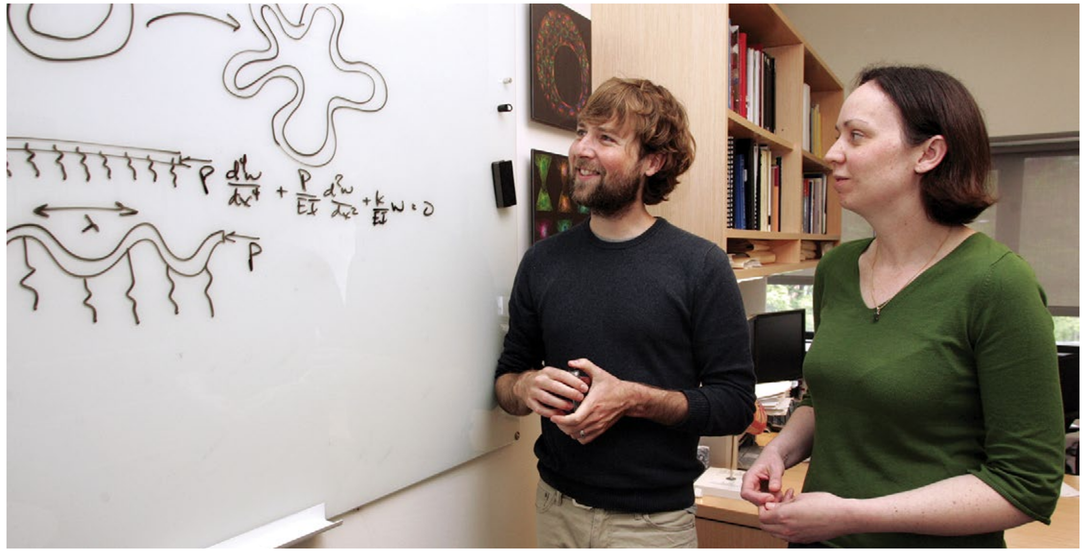


Photo by Frank Wojciechowski

Celeste Nelson and graduate student Victor Varner investigate the previously unrecognized mechanical factors that control how organs, such as lungs, develop.

Like a tree sprouting from an acorn, a lung grows from a small tube of cells into an array of branches and stems. But unlike trees, which assume a dizzying variety of shapes and sizes, the branched network of airways in the lung takes a single, predictable form in each species.

Until recently, biologists believed this complex, yet exacting shape was formed by localized regions of rapidly dividing cells, which bud collectively outward to produce new branches. But research led by Celeste Nelson, an associate professor of chemical and biological engineering at Princeton, indicates that in some types of lungs, branching is driven by cells changing shape rather than dividing.

In one experiment, for example, Nelson's team examined the development of the embryonic chicken lung. The lung begins as a tube of tissue, which sprouts buds that grow into the branches that conduct air. The researchers used a combination of mathematical modeling and experimental analysis to determine the physical and cellular mechanisms that initiate new airway branches.

Their results challenged the generally accepted view that localized patterns of cell division drive branching; instead, the researchers determined that changes in the shape of cells in the airway initiates new branches.

"Before branches form, the cells in the tube are roughly cube-shaped," said Victor Varner, a postdoctoral researcher in Nelson's lab. "These cells then become wedge-shaped at new branch points."

The conclusions in the experiment are specific to avian lungs, but the lab is pursuing similar work in mammals, Varner said.

"Understanding how these complex tissues form will help us recreate their structure and treat problems related to their development," Nelson said. "These blueprints might allow us to build replacement organs and treat congenital diseases as well as certain cancers."

Nelson's approach to investigating the development of tissues integrates several branches of engineering and biology.

Varner, whose undergraduate degree is in mechanical engineering and who worked at the NASA Johnson Space Center before coming to Princeton, said an important tool for the lab is mathematical modeling – writing sets of equations that describe the behavior of biological systems. Often, the complexity of embryonic tissues prevents a simple, intuitive understanding of their behavior, and math's broader gaze is needed to quantitatively investigate them.

"From a mechanical perspective, developing tissues are soft materials that undergo large deformations – materials that are constantly growing in response to different biochemical and physical cues," said Varner. "Mathematical models help us decompose these deformations into the part that's due to biological growth and the part that's due to the inherent elasticity of the tissue – how it responds to applied mechanical loads."

The team also takes advantage of a novel approach in experimentation. Using a technique that Nelson originally developed as a postdoctoral fellow at the Lawrence Berkeley National Laboratory, the researchers etch patterns of tiny wells into collagen, which are then filled with epithelial cells. The cells grow into three-dimensional tissues that researchers control by the shape of the collagen molds. The researchers are able to use the shapes to study how mechanical stress affects the pattern of branching of the tissue.

"This platform creates a way to control the tissue microenvironment in culture in a way that you cannot in an embryo," Varner said.

The researchers are extending their technique to examine other tissues that have implications for cancer research. The mammary gland, for example, also has branches, and the researchers are investigating how the gland's branched structure is formed during development.

The researchers believe that understanding the cues that drive these invasive growth patterns, whether in mammary gland tissue or in cancer, could hold the keys toward developing more effective therapies for cancer patients.

"This field is particularly exciting because there is so much to learn, and anything we uncover may lead to promising new strategies to improve human health," Nelson said. **E**

MAPPING *the* FIRST STEPS *in* LIFE

Life begins as a collection of cells, but the journey from that tiny grouping to a fully developed organism is complex and mysterious. Stanislav Shvartsman, a professor of chemical and biological engineering and the Lewis-Sigler Institute for Integrative Genomics, brings an engineering perspective to studying mechanisms involved in tissue development and form. In one promising approach, Shvartsman's lab is using mathematical modeling and experiments on fruit fly embryos to better understand chain reactions of enzymes that control cellular behavior. One enzyme currently being studied by Shvartsman's team, called MAPK, is believed to control the development of structures ranging from compound insect eyes to the mammalian brain. Shvartsman has discovered key mechanisms in cells that affect and are affected by MAPK. "There is still much to learn but our understanding of these very complex systems is growing steadily," Shvartsman said. "It is a very exciting time."

Photo by Frank Wojciechowski

The image below shows thin slices of a part of fruit fly embryos where stem cells turn into mature eggs. Created by graduate students Yogesh Goyal and Bomyi Lim and postdoctoral researcher Miriam Osterfield, the image was selected for display in Princeton's 2014 "Art of Science" competition. **–JS**

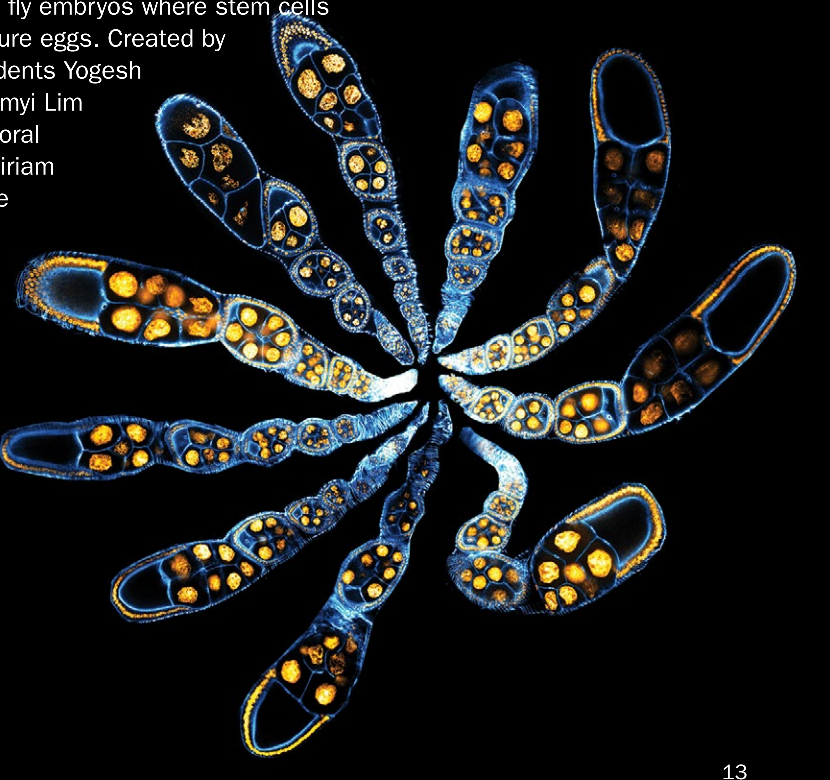


Image courtesy of Olga Troyanskya

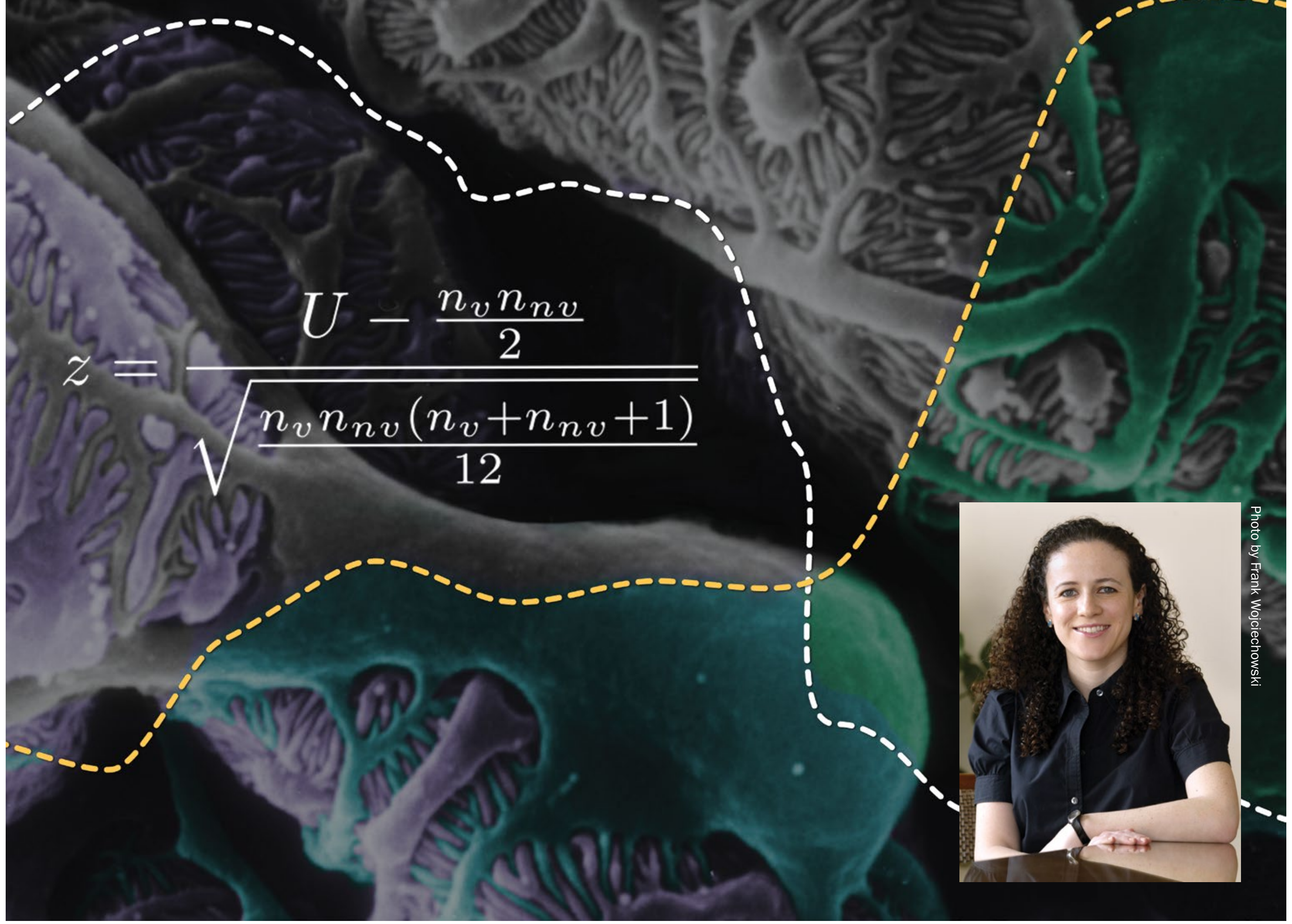


Photo by Frank Wojciechowski

MATCH MAKING: COMPUTER SCIENCE CONNECTS GENES TO TISSUES

by John Sullivan

Olga Troyanskaya and her colleagues are making great strides in dissecting tiny collections of human cells, but they are not using scalpels.

They are using data.

Troyanskaya, a postdoctoral fellow and graduate students at Princeton have developed a system that allows computers to "virtually dissect" a kidney in a way that surgery cannot. The computer uses data from an array of measurements in kidney biopsies to separate cells mathematically and identify genes that are turned on in a specific cell type.

"We call it in-silico nano-dissection," said Troyanskaya, a professor of computer science and the Lewis-Sigler Institute for Integrative Genomics.

The method has proven to be far faster and significantly more effective than current techniques. In findings published recently in the journal Genome Research, Troyanskaya's group and a team of researchers at the University of Michigan led by Matthias Kretzler reported that they had identified 136 genes involved in the creation of a critical kidney cell called a podocyte. In decades of research, only 46 had been previously identified.

"The potential for this is huge," said Behzad Najafian, a University of Washington assistant professor of pathology who specializes in renal pathology. "I believe this novel technique, which is a significant improvement in cell lineage-specific gene-expression analysis, will not only help us understand the pathophysiology of kidney diseases better through biopsy studies, but also provides a strong tool for discovery or validation of cell-specific urine or plasma biomarkers."

The researchers focused on the glomerulus, an area of the kidney where the podocyte cells filter the waste from blood that will eventually leave the body as urine. One of the main reasons the researchers chose to track the podocytes is that the tiny cells are frequently involved in kidney disease. The researchers wanted to identify genes active in the podocytes and thus determine which genes cause the cell to be able to perform the podocyte's filtering function, differentiating it from other cell types in the kidneys.

It is not an easy job: even a biopsy precise enough to sample only the glomerulus leaves doctors with a mix of four cell types including the podocyte. This yields activity measurements for tens of thousands of molecular markers, called RNA.

"It's a little more complicated than this, but you can think of RNA as the instructions that come from the DNA, and we need to identify which of these instructions are active in the podocytes" said Casey Greene, who worked on the project as a postdoctoral researcher with Troyanskaya and is now an assistant professor of genetics at Dartmouth College.

Kretzler, a professor of internal medicine and computational medicine, and his team in Michigan first obtained data from the biopsies of 452 patients, each containing RNA from roughly 20,000 genes. The more RNA found in the sample from a particular gene, the more active that gene.

By searching for patterns among the patients' data, the team identified 136 genes linked to the podocytes. Two of those genes have been shown experimentally to be able to cause kidney disease. The computer's identification of genes linked to podocytes was verified by staining the cell samples with antibodies – each of which reacts to a specific protein constructed from the RNA instructions. The researchers found that the computer's predictions were 65 percent accurate. The accuracy of the best existing method, which involves experimentally isolating the podocyte cells in mice and measuring their expression patterns, is only 23 percent.

Troyanskaya said the goal is to train the computer to come up with a mathematical formula that identifies links between similar patterns and what distinguishes them from other, unrelated patterns. It is essentially the general type of approach that companies use to evaluate customers' buying habits to suggest new movies or purchases.

"The genes that we know are specifically active in podocytes – they are the movies that we like," Troyanskaya said.

Although the researchers used kidney cells, Troyanskaya said the program also will work with other cell types, including other solid tissues that cannot be experimentally microdissected in humans. The program is available free to researchers on Princeton's website.

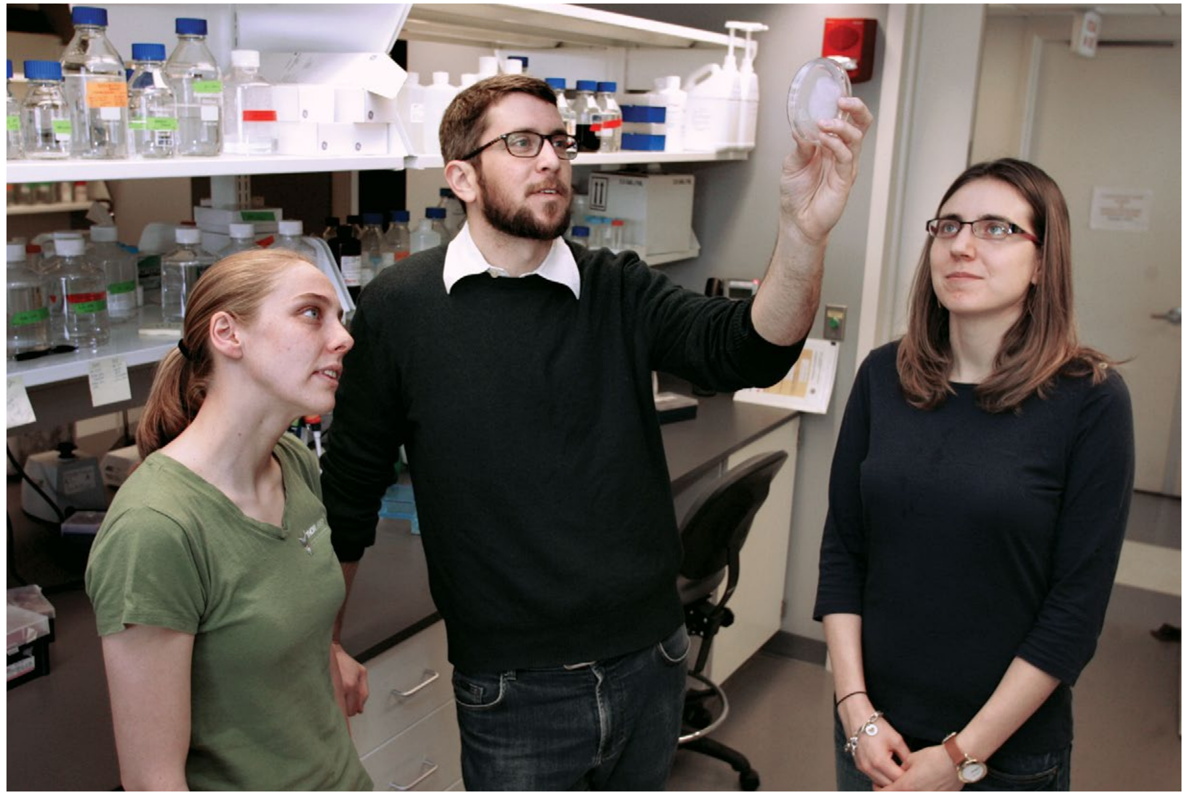
In addition to Greene, Troyanskaya's team at Princeton included Young-suk Lee and Qian Zhu, graduate students in computer science and genomics. The group collaborated with Kretzler's team at Michigan as well as researchers at the University of Zurich and at Fondazione IRCCS Ca' Grande Ospedale Maggiore Policlinico in Milan. **E**

The photo illustration (opposite) depicts a specialized type of cell within the kidneys, podocytes, and a mathematical concept that Professor Olga Troyanskaya (inset) devised to virtually dissect those cells from others in a complex tissue sample.

WHY ARE CELLS *small?*

by Anna Azvolinsky

Photo by Frank Wojciechowski



From left, postdoctoral researcher Stephanie Weber, Assistant Professor Clifford Brangwynne and graduate student Marina Feric study the physical and chemical characteristics of important clusters of molecules within cell nuclei. Their work led to a fundamental discovery about the likely role of gravity in limiting the size of cells.

What goes up must come down – even inside the miniscule world of cells.

Biologists have generally discounted gravity's effect on cells because it was thought that the average cell is too small for gravity to play a role in its structure. But Princeton researchers Clifford Brangwynne and Marina Feric have found that gravity helps constrain how large cells can grow. The results provide a novel reason why most animal cells are small and of similar size.

"Gravity becomes really important at a smaller scale than you might have guessed," said Brangwynne, an assistant professor of chemical and biological engineering who led the research.

While studying what makes large particles in the nucleus of the African clawed frog's egg cells stay in place, Brangwynne and Feric, a graduate student, observed the particles falling to the bottom of the nuclei when a scaffolding inside the cells was disturbed.

The researchers, who published their findings in the journal Nature Cell Biology, concluded that when a cell reaches a certain size, it becomes subject to gravitational forces that require a scaffolding to stabilize the internal components. Below that threshold size, the internal components of a cell float freely, buoyed by smaller chemical forces.

"The research is really elegant and novel," said Zemer Gitai, an associate professor of molecular biology at Princeton, who was not involved in the research. "Cells almost certainly evolved to be [small enough] to ignore the effects of gravity."

The typical animal cell has a diameter of about 10 microns (10 millionths of a meter). Larger cells, like the egg cells of the African clawed frog, are up to 1 millimeter in diameter, but examples of such large cells are not frequent. Scientists have attributed this size limit to the difficulty that large-volume cells have obtaining nutrients, an explanation Brangwynne said is not backed by substantial evidence.

Brangwynne and Feric were not thinking about gravity when they began their investigation. Brangwynne wanted to find out why certain types of large particles within cells fuse together upon contact, like water droplets, when floating freely in a cell but not when they are in the cell's nucleus. By injecting various size plastic beads into the nucleus of the frog egg cells, Branwynne and Feric found evidence for an invisible scaffold that might keep the particles from fusing.

Feric next discovered that this matrix could be made up of fibers of the protein actin, which was known to form a cytoskeleton in the parts of cells outside of the nucleus but whose role in the nucleus was not clear. To test the role of this actin scaffold, the researchers rid the nuclei of the actin polymers, either by treating the nuclei with drugs against the protein, or by making the nucleus pump out the protein.

"When we did this experiment we found the large particles sank like pebbles to the bottom of the nucleus. That was genuinely shocking," said Brangwynne.

Noting that actin is less abundant and does not appear to form an extensive mesh in smaller cells, Feric's experiments led the researchers to deduce that larger cells have the actin mesh to protect against gravity.

They propose that gravity becomes important at a certain particle density and a cell size of roughly 10 microns – the size limit of most animal cells. The actin in these large nuclei keeps the particles in place as a support against gravity.

Particles in a cell become proportionally larger with increasing cell size. A particle in a small cell is like a single piece of dust – it floats well, unhindered by gravity. But particles in larger cells are like many pieces of dust clustered together that have a greater mass and require support to stay buoyed.

Feric and Brangwynne plan to repeat the experiments in different-sized cells and explore the properties of the actin network in the nucleus to understand the limits of its strength.

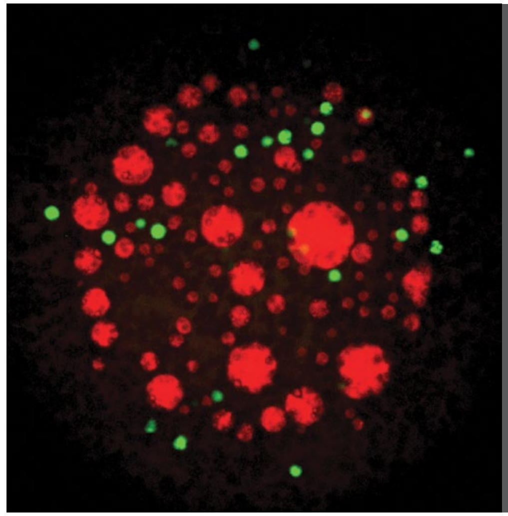
The researchers said a rewarding aspect of the study was its surprising turns, which at one point led them to calculate the viscosity of the nucleus to understand the behavior of the beads they injected.

"We had absolutely no intention of trying to learn about gravity," said Brangwynne.

"That you need to know the viscosity of the cell nucleus to figure out that gravity could be important for setting the upper limits of cell size? It's hard to imagine how one could predict such a connection."

In an undergraduate course Brangwynne teaches, students have previously performed calculations suggesting gravity is a negligible force on cells. Brangwynne said he will now have to change the exercise. "This is where the research ends up influencing the class work."

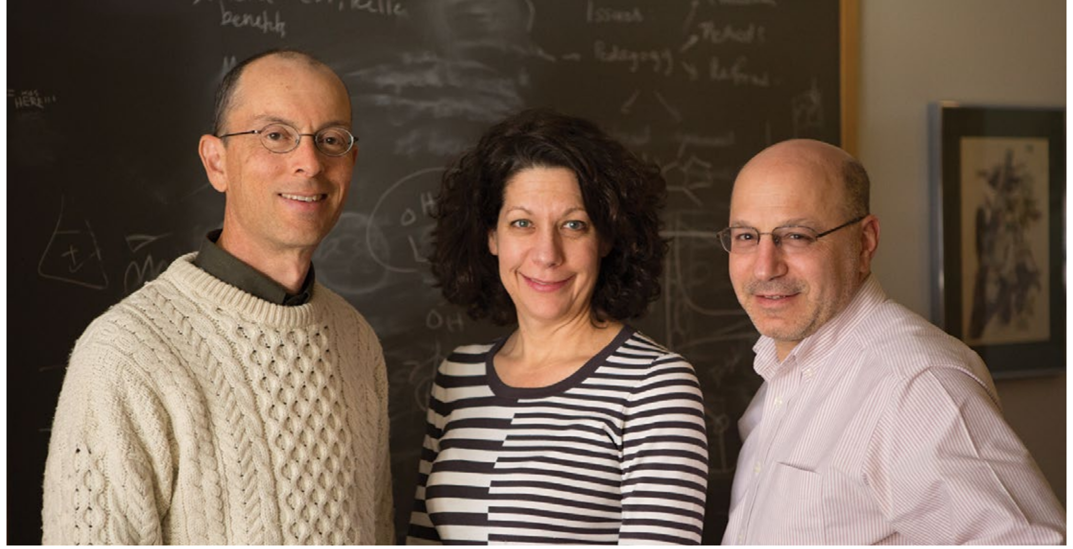
The research was supported by a New Innovator Award from the National Institutes of Health and a Searle Scholar Award, both awarded to Brangwynne in recognition of outstanding work as a young scientist. E



Researchers in the Brangwynne lab captured microscope images of particles called nucleoli (shown in red) within the nucleus of a frog egg. When they disrupted a chemical scaffold within the cell, their images showed the nucleoli fell to the bottom of the nucleus. In small cells, the particles likely would not need the scaffold because other chemical forces would keep them afloat; in bigger cells the effects of gravity become significant.

TRANSFORMATIVE
TECHNOLOGIES

by Catherine Zandonella



Photos by Denise Applewhite

Princeton researchers, from left, Ned Wingreen, Bonnie Bassler and Howard Stone have received a Schmidt Fund for developing a microscope to explore bacterial biofilms.

Princeton engineers are part of the two research teams awarded funding in 2014 through the University's Eric and Wendy Schmidt Transformative Technology Fund. The fund aims to foster technologies that have the capacity to transform entire fields of inquiry but may be considered too risky or forward-looking to obtain funding from traditional sources.

A microscope for probing bacterial films

Experts of self-preservation, bacteria can grow into sheets known as biofilms that evade antibiotics, clog medical devices, and foul water filters and pipes. To counter these negative effects, a team of Princeton researchers is developing a microscope to peer inside the slimy mantle and find the genes that make biofilms so successful.

"We want to ask, at the single-cell level, what chemical and physical and mathematical rules are underpinning the assembly of these films, and then we want to do something about it," said Bonnie Bassler, the Squibb Professor in Molecular Biology. Bassler is co-leading the project with Ned Wingreen, the Howard A. Prior Professor of the Life Sciences, and Howard Stone, the Donald R. Dixon '69 and Elizabeth W. Dixon Professor of Mechanical and Aerospace Engineering.

An early version of the microscope was developed by Princeton postdoctoral researcher Knut Drescher, who is jointly advised by Bassler, Stone and Wingreen. The Schmidt Fund will enable the team to add to the microscope's capabilities.

The existing microscope has enabled the researchers to observe how biofilms develop, cell by cell, when fluids are flowing past the cells. In nature, biofilms are influenced by the forces that fluids exert on bacterial cells as they gather to form the biofilm and communicate with each other.

The improved microscope should allow the researchers to find whether cells from certain parts of the biofilm, such as the edge that faces the fluid, have special attributes.

"It is like taking a city apart, one high-rise at a time," said Stone, whose expertise is on fluid dynamics. "We want to know what structures are there, and what their functions are."

The researchers will apply two techniques for interrogating cells: optogenetics, which involves using laser light to turn on and off individual genes, and deep sequencing of the cellular genes.

"There are very strong hints that the cells in biofilms take on different roles depending on their locations, but imaging alone cannot tell you that," said Wingreen. "The beauty of optogenetics is that we can manipulate individual genes in specific cells to unpack what all of these different interactions are doing."

A new technology for 3-D imaging at the nanoscale

Electronic technologies of the future as well as investigations of cells and other biological materials depend on parts that are just nanometers – billionths of a meter – in size. Supported by the Schmidt Fund, Princeton researchers are developing an instrument for measuring the nanoscale properties of thin films of plastic and biological materials known generally as "soft matter," which are neither simple liquids nor crystalline solids.

The instrument will measure the flow of small amounts of soft matter in three dimensions, including structures in living cells. Called a 3-D NanoRheometer – a rheometer is a device that measures flow – the instrument will help researchers explain the behavior of plastics and other soft matter restricted to confined environments.

The device will fill an important gap in the needs of researchers, explained project leader Rodney Priestley, an assistant professor of chemical and biological engineering.

"Nanostructured materials behave differently than the same materials in a larger quantity," he said. "To advance technology, there is a need to develop experimental techniques that allow us to find out why that is."

Along with Priestley, the team members are Craig Arnold, professor of mechanical and aerospace engineering; Clifford Brangwynne, assistant professor of chemical and biological engineering; and Richard Register, the Eugene Higgins Professor of Chemical and Biological Engineering. The four professors are associated with the Princeton Center for Complex Materials.

Researchers currently use microscopes to track nanomarkers (particles 9,000 times smaller than a human hair's width) in soft matter, but this method performs poorly at tracking particles in three dimensions.

"If the nanomarkers move toward or away from the microscope, they will move out of focus and you won't be able to detect them," Arnold said.

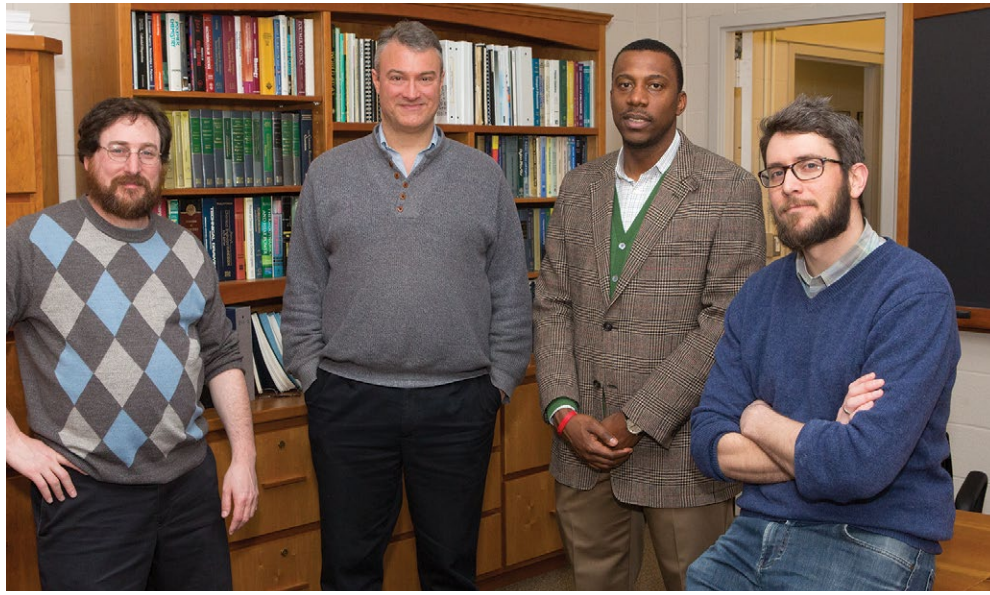
A new, fast-focusing microscope lens developed by Arnold's research group will be employed to help solve this problem.

One of the first tasks in the two-year program will be to engineer a system that can rapidly – or even simultaneously – acquire scans of the nanomarkers at varying depths embedded in plastics. The team will also integrate a second imaging system to enhance the results, and develop a computer program to combine the scans into images of the nanomarkers' movements.

In the second year of the program, the researchers will expand the use of the 3-D NanoRheometer to study structures in living cells and explore how these relate to cellular health, said Brangwynne, whose group studies the self-assembly of biological materials.

Register and Priestley also will use the technology to gain insight into the properties of new types of polymers, which have many industrial uses. "The Schmidt Fund is invaluable in making this project possible," Register said. "These sorts of opportunities make it great to be at Princeton." **E**

Princeton researchers, from left, Craig Arnold, Richard Register, Rodney Priestley and Clifford Brangwynne have received a Schmidt Fund for developing a technology for 3-D imaging at the nanoscale.



LASSOING *A* UNIQUE SHAPE *FOR* NEW MEDICINES

by John Sullivan

Graduate students Mikhail Maksimov (standing) and Alan Futran work in the lab of Associate Professor James Link BSE '00 where they investigate protein segments called lasso peptides, which promise to have multiple uses in medicine.

Among the baroque shapes of molecular biology, with its twisting proteins and spiraling nucleic acids, the lasso peptide stands out: like a rope spun by a tiny cowboy, it is a trailing whip of amino acid topped with a distinct lasso.

The shape is not just aesthetically interesting. Scientists like James Link BSE '00 believe that the lasso peptide might serve as a scaffold upon which entirely new drugs and medical therapies can be constructed. In fact, several lasso peptides naturally have therapeutic effects: some kill a specific type of bacteria; another binds to a part of liver and kidney cells that controls glucagon, which is important in diabetes.

"This structure is something that nature seems to have used to carry out a lot of different functions that are medically relevant," said Link, an associate professor of chemical and biological engineering. "Among other things, our research is looking into whether they may lead to an entirely new way of making drugs."

Peptides – and their larger cousins, proteins – are long chains of amino acids. The large size of these molecules provides a critical functional benefit in biology. Their complexity allows them to perform highly specialized tasks for organisms such as fighting infection, copying DNA and carrying out chemical reactions in cells.

This complexity also holds great potential for medicine. Currently, most drugs are made of small molecules that perform relatively simple tasks within the body. But Link and his co-researchers believe that larger molecules can eventually be harnessed to create drugs that perform far more complex actions.

"The possibilities are endless," said Mikhail Maksimov, a graduate student in the lab who has written several papers on lasso peptides with Link and won a Dodds Fellowship for his fifth year of study at Princeton.

The downside, for medical science, is that most large molecules' complexity leads to instability. Storing and working with peptides and proteins is formidably difficult and in many cases impractical because of their innate fragility.

That is where the lasso peptide stands out. It is far larger than small molecules typically used in medicine, but far more stable than conventional peptides and proteins. The secret to its stability is its knotted shape.

"Enzymes called proteases, which slice up peptides and proteins, are a main cause of instability for molecules inside the body," Link said. "The knotted shape of the lasso peptide renders them largely resistant to proteases."

Some particularly resistant lasso peptides can even stand up to the protease-rich environment of the digestive tract, an area normally off-limits to therapeutic proteins and peptides.

"Lasso peptides have multiple benefits – they are small enough to work with and they are stable," Maksimov said. "At the same time, they have a degree of complexity that allows us to do many things with them."

Link's lab is conducting several projects looking into "grafting" molecules with known therapeutic effects onto a lasso-peptide scaffold.

"Since nature has already used the lasso-peptide scaffold for therapeutic purposes, we are excited about the possibility of re-engineering lasso peptides to make completely new drugs that nature has not explored," Link said.

Link also is looking for additional lasso peptides to serve as potential scaffolds. Since they were discovered in 1991, only 30 distinct lasso molecules have been identified, with more than half discovered in the last two years. Partly, that is because the molecules are produced by bacteria, and only under the right conditions. So researchers not only need to know which bacteria will make the molecules, they also need to know how to stimulate their production.

Link's lab, however, has developed an alternative approach to discovery.

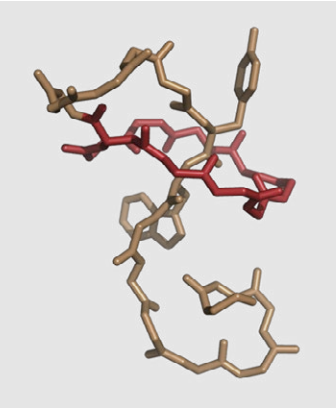
"Right now, we don't understand enough about the limitations of lasso peptides or how far we can push the scaffold," Maksimov said. "We are trying to find more examples in nature."

To accomplish this, the researchers have studied the DNA sequence of bacteria known to produce lasso peptides in search of characteristics that could be mirrored in other organisms. In a series of recent publications, the team has identified 98 potential lasso peptide producers from 78 gene clusters on different organisms.

The next step is to stimulate the organisms to produce the lasso peptides in a lab – "not a trivial task," according to Maksimov. Often, the researchers will take a genetic sample from a lasso-peptide producer and graft it into a microbe like E. coli that is easy to work with. Using this technique, Link's lab has produced a number of previously unknown lasso peptides.

At the same time, the lab is working on identifying the functions of the new lasso peptides.

"We have developed robust tools to discover and produce new lasso peptides," Link said. "Based on our analysis, there are dozens more to find. Our next goals are to find the role of these lasso peptides in bacterial physiology and to turn them into new ways to combat disease." **E**



The Link lab investigates a type of molecule called "lasso peptides," named for their resemblance to a rope lasso – a ring at the top with a tail extending beneath. These molecules play important biological functions in bacteria and show promise as a structure for making new generations of medicines.

ENGINEERS ELECTED TO NATIONAL ACADEMIES


Robert Schapire


Photo by Denise Applewhite

Howard Stone

Two members of the engineering faculty, computer science professors **Jennifer Rexford** BSE '91 and **Robert Schapire**, were elected this year to the National Academy of Engineering. Membership in the academy is among the highest honors bestowed on engineers in the United States.


Jennifer Rexford

Rexford, the Gordon Y.S. Wu Professor in Engineering, was recognized for her "contributions to the operational stability of large computer networks," the academy said in a news release. An expert in Internet routing and network management, Rexford is a member of the Federal Communications Commission's Open Internet Advisory Committee and coordinates the committee's group on mobile broadband networks.

Schapire, the David M. Siegel '83 Professor in Computer Science, was honored for "contributions to machine learning through invention and development of boosting algorithms," the academy said.

A specialist in machine learning, Schapire is best known as a primary developer of a technique called boosting in which many weak and inaccurate prediction methods are combined to form a highly accurate predictor. Since it was first proposed by Schapire and his colleague Yoav Freund, now a computer science professor at the University of California-San Diego, boosting algorithms have been used in a wide variety of applications.

Howard Stone, the Donald R. Dixon '69 and Elizabeth W. Dixon Professor in Mechanical and Aerospace Engineering, and **Sergio Verdú,** the Eugene Higgins Professor of Electrical Engineering, were named to the National Academy of Sciences. Founded by Congress in 1863, the Academy of Sciences is made of members elected by their peers based on outstanding contributions to scientific research.

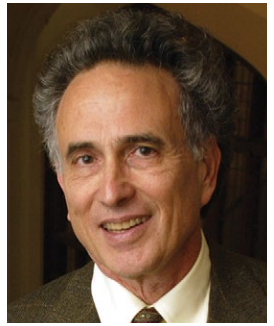

Photos by Frank Wojciechowski

Sergio Verdú

Stone's research has explored fundamental problems in fluid motion and evaluated a wide range of affects including surface tension, buoyancy, fluid rotation and surfactants. His work combines theory, modeling, computer simulation and experimentation to examine flow phenomena.

Verdú, an expert in information theory, examines the fundamental limits of information transmission and compression. Among many other areas, his work has contributed to multi-user detection, which is used in communications to distinguish a signal from background interference.

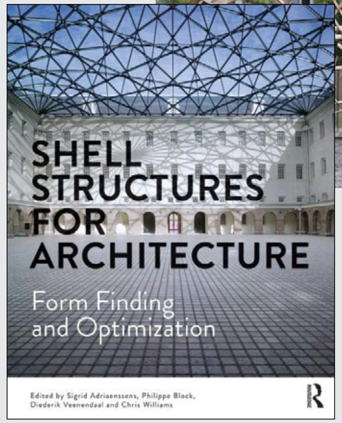
Robert Socolow, senior research scholar and professor emeritus of mechanical and aerospace engineering, was elected to the American Academy of Arts and Sciences. Founded in 1780, the academy's membership of roughly 5,000 includes some of the world's foremost scholars.


Robert Socolow

Socolow's current work focuses on global carbon management and fossil-carbon sequestration. He is the co-director of Princeton's Carbon Mitigation Initiative and co-author of the seminal work on climate "stabilization wedges" in 2004.

SHELL STRUCTURES FOR ARCHITECTURE: FORM FINDING AND OPTIMIZATION

In a volume that combines art-book images and rigorous engineering, Sigrid Adriaenssens and an international team of colleagues introduce professionals and students to shell structures and the techniques needed to make these complex and elegantly thin surfaces. Beautiful forms often emerge from underlying mathematics and physics, said Adriaenssens, an assistant professor of civil and environmental engineering. "The context of gravity is our playground," she and colleague Laurent Ney write. "This design driver is a hard constraint but gives birth to a realm of intriguing complex spatial structural shapes."

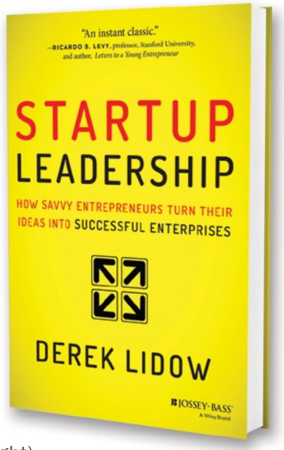


Faculty, students and staff from across the University gathered May 30 in the Engineering Quadrangle courtyard to celebrate the publication of the book "Shell Structures for Architecture." On display during the event was a dome structure designed by graduate student Yousef Anastas and assembled by four students in one day.


Photo by Zach Donnell

STARTUP LEADERSHIP: HOW SAVVY ENTREPRENEURS TURN THEIR IDEAS INTO SUCCESSFUL ENTERPRISES

Derek Lidow BSE '73, a lecturer in electrical engineering and at the Keller Center, offers his experience from a distinguished business career to help guide entrepreneurs through the difficult stage of moving from a startup to a self-sustaining business. A founder must have a very personal "fire in the belly" as well as genuine empathy that makes it worthwhile for others to follow the vision, Lidow said. "There has to be a balance between tremendous selfishness and also selflessness on the part of the founder if they really want to take it all the way."



The Keller Center hosted a reception May 20 to celebrate the launch of the book "Startup Leadership" by Derek Lidow (above right). Lidow, a successful entrepreneur and business leader, developed the book out of his teaching at Princeton, where he has led the creation of three entrepreneurship courses.

RECENT FACULTY AWARDS

CHEMICAL AND BIOLOGICAL ENGINEERING

Clifford Brangwynne
Sloan Fellow

Pablo Debenedetti
Benjamin Garver Lamme Award, American Society for Engineering Education

Christodoulos Floudas
Honorary doctorate, Abo Akademi University
National Award and Gold Medal, Hellenic Operational Research Society
AIChE Fellow


Rodney Priestley

Athanassios Panagiotopoulos
Fellow, American Institute of Chemical Engineers

Rodney Priestley
Camille Dreyfus Teacher-Scholar
Sloan Fellow
Presidential Early Career Award for Scientists and Engineers

Sankaran Sundaresan
Fellow, American Association for the Advancement of Science

CIVIL AND ENVIRONMENTAL ENGINEERING

Michael Celia Ph.D. '83
Honorary Membership Award, International Society for Porous Media

Branko Glišić
Highly Commended Award, Chartered Institute of Building (with **Naveen Verma***)*

Eric Wood
Alfred Wegener Medal, European Geosciences Union

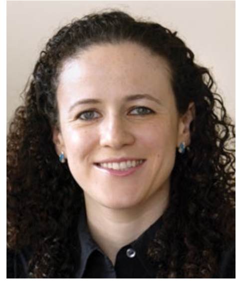

Branko Glišić

COMPUTER SCIENCE

Mark Braverman
Packard Fellowship

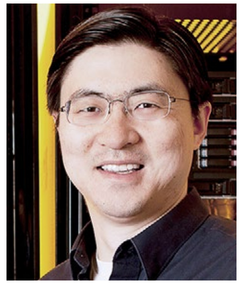
Thomas Funkhouser
Computer Graphics Achievement Award, SIGGRAPH

Jennifer Rexford BSE '91
Named to "Ten Cloud Trailblazers for 2013" by GigaOM


Olga Troyanskaya

Olga Troyanskaya
(COS and Genomics)
Ira Herskowitz Award, Genetics Society of America

ELECTRICAL ENGINEERING


Mung Chiang

Mung Chiang
Guggenheim Fellow

Stephen Chou
IEEE Pioneer Award in Nanotechnology
Fellow, National Academy of Inventors

Paul Cuff
Career Award, National Science Foundation

Claire Gmachl and **Gerard Wysocki**
Top-cited Paper Award, Chemical Physics Letters

H. Vincent Poor Ph.D. '77
Foreign Member, Royal Society of London
Member, Academia Europaea
Honorary Doctorate of Science in Technology, Aalto University, Finland (Oct. 2014)
Booker Gold Medal, URSI (Int'l Scientific Radio Union)
Elected to National Academy of Engineering Governing Council

Barry Rand (ELE and Andlinger Center)
3M Nontenured Faculty Award

Sergio Verdú
Corresponding Member, Royal Academy of Engineering of Spain

Naveen Verma
Highly Commended Award, Chartered Institute of Building (with **Branko Glišić***)*
Young Investigator Program Award, AFOSR

David Wentzlaff
Young Investigator Program Award, AFOSR

MECHANICAL AND AEROSPACE ENGINEERING

Emily Carter (MAE and Andlinger Center)
Sigillo D'Oro, Societa Chimica Italiana
Remsen Award, ACS Maryland Section

Wole Soboyejo
U.N. Scientific Advisory Board

OPERATIONS RESEARCH AND FINANCIAL ENGINEERING

Jianqing Fan
Guy Medal in Silver, Royal Statistical Society

Warren Powell BSE '77
Honorary doctorate, University of Québec at Montréal

Ramon van Handel
Presidential Early Career Award for Scientists and Engineers

Robert Vanderbei
Fellow, American Mathematical Society


Emily Carter

SATISFYING 'LONGING TO LEARN,' FACULTY HONORED FOR TEACHING

Three members of the engineering school faculty were recognized this year for outstanding accomplishments in teaching and mentoring students.

Claire Gmachl, the Eugene Higgins Professor of Electrical Engineering, received the President's Award for Distinguished Teaching. She was one of four faculty members who received the award during Commencement ceremonies June 3.

Gmachl is a leader in the development of quantum laser cascades for environmental and medical applications. Since joining the Princeton faculty in 2003, she has created several courses, including the school's graduate-level research ethics class, and has served as vice dean of the engineering school. A colleague said that Gmachl has gone beyond her specialty to create courses for non-science majors such as "New Eyes for the World," which shows how optics can be used for environmental and medical applications. A former graduate student now beginning a career as a professor praised Gmachl's ability "to motivate each student to grow as a scientist."

Sigurd Wagner, a professor of electrical engineering, received the Graduate Mentoring Award from the McGraw Center for Teaching and Learning. He was one of five faculty members who received the award during the Graduate School's Hooding Ceremony June 2.

Wagner, who joined the engineering faculty in 1980, specializes in flexible large-area electronics. His research focuses on devices such as thin solar cells, medical sensor arrays, and textiles that incorporate electronics. He is also working on methods to include flexible electronics into other systems. One graduate student said that "Professor Wagner has been an impeccable guru in my graduate life at Princeton." Another noted that Wagner was "always willing to chat, whether at 9 a.m. on Sunday or 9 p.m. on weekdays."

Celeste Nelson, an associate professor of chemical and biological engineering, received the School of Engineering and Applied Science Distinguished Teaching Award.

Nelson, who joined the Princeton faculty in 2007, specializes in developmental biology. Her research includes studies of morphogenesis and tissue engineering, and she has developed two highly successful elective courses in biomedical engineering. One course was originally capped at 60 students but demand was so high that enrollment had to be raised to 80 students. Nelson is also known for teaching students from many different fields of study beyond chemical and biological engineering. One student said, "Professor Nelson introduced me to the material I had been longing to learn since the beginning of my engineering education."


Claire Gmachl


Sigurd Wagner

Photo by Danielle Alio

Derek Lidow (center) created the course “Creativity, Innovation and Design,” which involved flexible use of physical spaces to spur creative problem-solving. Hear Lidow and students in the class describe the “wicked problem” they tackled: http://bit.ly/LidowClass.

TACKLING ‘WICKED PROBLEM,’ KELLER CLASS STOKES CREATIVITY

Anyone walking through the H wing of the Engineering Quadrangle this past spring may have passed a classroom with 14 students jumping up and down, stretching, playing mind games on whiteboards and drinking coffee.

The scene was a normal start for ERG 392, “Creativity, Innovation and Design,” a new class offered by the Keller Center at Princeton. If the opening antics were unusual, they were just a warm-up for what was to come.

The class focused on fostering creativity and encouraged a different way of thinking about real-world problems. Open to undergraduates across all departments, the course was taught by Derek Lidow BSE ’73, a professional specialist and lecturer in electrical engineering and the Keller Center.

“The University tends to focus students on convergent thinking, how to come up with the best answer, and so students don’t get a chance to practice divergent thinking, coming up with all sorts of possible solutions,” Lidow said. “That’s what this class is really good at.”

With flexible seating and rolling white boards, the classroom was created specifically for Lidow’s class. It has the capability to be reconfigured at any moment to encourage a flow of ideas.

For a final project the students tackled what Lidow called a “wicked problem” that has defied solutions for ages: Design a product or service to mitigate high-risk drinking on Princeton’s campus. Student teams came up with a wide range of designs including a cup that accurately shows how much alcohol it contains, and a new way to provide alcohol education through online sharing of personal experiences. A panel of University officials who watched the final presentations encouraged the students to continue perfecting the ideas for possible implementation across campus.

“Creativity usually isn’t something you think you can learn, and so this class is unique in that it gives you the tools and the opportunities to practice it,” said Yolanda Yeh, a member of the Class of 2015 and electrical engineering major. “A lot of what I’m taking away is being really creatively conscious, thinking about applying creativity to different places and also the specific techniques you use to develop empathy for your users or to act on your feedback.” **–Danielle Alio**

Photos by Frank Wojciechowski

Celeste Nelson (far left), winner of the School of Engineering and Applied Science Distinguished Teaching Award, and Dean H. Vincent Poor Ph.D. ’77 (far right) stand with recipients of awards at the school’s Class Day ceremony June 2. Below, from left: Buse Aktas; Katherine Pogrebniak; Assistant Professor Branko Glišić with his advisees Eliza Learner, Shue-Ting Ellen Tung and Katherine Flanigan; Anna Kornfeld Simpson and her sister Sara.

STUDENTS CELEBRATED FOR RESEARCH AND SERVICE

The Princeton Class of 2014 included 245 students from the engineering school – 223 BSE degrees and 22 who received an A.B. in computer science. At Class Day ceremonies June 2, the School of Engineering and Applied Science gave the following awards.

J. Rich Steers Award
Eliza Learner
Civil and Environmental Engineering
Kyle O’Neil
Mechanical and Aerospace Engineering

Jeffrey O. Kephart ’80 Prize in Engineering Physics
Alexander Creely
Mechanical and Aerospace Engineering

Prism-Newport Award in Photonics
Callie Woods
Electrical Engineering

Tau Beta Pi Prize
Shue-Ting Ellen Tung
Civil and Environmental Engineering

Joseph Clifton Elgin Prize
Buse Aktas
Mechanical and Aerospace Engineering

George J. Mueller Award
Katherine Flanigan
Civil and Environmental Engineering
Kevin Ross
Civil and Environmental Engineering

Calvin Dodd MacCracken Senior Thesis/Project Award
Abigail Ward
Electrical Engineering

Lore Von Jaskowsky Memorial Prize
Anna Kornfeld Simpson
Computer Science
Karen Wang
Mechanical and Aerospace Engineering

James Hayes-Edgar Palmer Prize In Engineering
Katherine Pogrebniak
Computer Science

GRADUATE STUDENTS PUSH RESEARCH FRONTIERS

Studying resistance of bacteria and cancers to attack by chemicals, analyzing how food trade redistributes water resources around the world, finding hidden patterns in data – these are a few of the projects graduate students at Princeton Engineering have advanced in the past year. At the intersection of teaching and research, graduate students are preparing to become the next generation of leaders in their fields.

CAROLE DALIN
CIVIL AND ENVIRONMENTAL ENGINEERING

Hometown: **Le Havre, France**
Previous institution: **École Centrale Paris**
Dalin's research focuses on the use of water resources for food production, and on the way these water resources are "virtually" exchanged between countries as they trade agricultural products. In a study published in the Proceedings of the National Academy of Sciences, Dalin found that international food trade has led to an increasingly efficient use of global water resources, with relatively more water-efficient countries exporting to less efficient ones. More recently, she has investigated the policy aspects of her research, analyzing virtual water trade between Chinese provinces. Dalin currently is combining hydrological and integrated crop-economic models to evaluate future food trade and associated water uses under different climate and policy scenarios in China.

ZACHARY FEINSTEIN
OPERATIONS RESEARCH AND FINANCIAL ENGINEERING

Hometown: **Hastings-on-Hudson, New York**
Previous institution: **Washington University**
Feinstein has been studying systemic risk, such as the risk of contagion between banks, which is of increased importance since the financial crisis of 2008. Due to the interconnected nature of banks, bankruptcy of one institution affects the balance sheet of others. When the negative impacts are enough to cause other banks to default on debts, the financial system is imperiled. Studying systemic risk measures, Feinstein is mathematically defining a set of capital requirements for each financial institution so that the risk of the entire financial system is controlled. His approach includes using multiple currencies to hedge risks so capital requirements in times of uncertainty can be met in multiple ways.

PREM GOPALAN
COMPUTER SCIENCE

Hometown: **Bronx, New York**
Previous institution: **Purdue University**
Gopalan is developing scalable algorithms for uncovering hidden patterns in massive data sets. His algorithms have discovered hidden structures such as overlapping communities in social networks, patterns of user preferences in consumer data, and genomic structure of populations. These patterns can be used in making predictions – for example, a list of articles that a scientist will want to read next. Gopalan's algorithms emerge from Bayesian inference, a common statistical technique that he is augmenting with other techniques to make scalable to large data sets. Using this approach, he is developing algorithms to learn population structure from genotype data and working with colleagues at Microsoft Research to create recommendation systems.

JONATHAN ROBINSON
CHEMICAL AND BIOLOGICAL ENGINEERING

Hometown: **Fort Collins, Colorado**
Previous institution: **Colorado State University**
Robinson is investigating how nitric oxide, an important antimicrobial chemical generated by our immune system, exerts its antibacterial effect, and how bacteria respond and adapt to this stress. He has constructed a computational model of the biochemical network that interacts with nitric oxide in *E. coli*. Using the model, he has discovered novel features of the network, including the previously unknown role of an *E. coli* enzyme in protecting the bacteria against nitric oxide. His model serves as a valuable predictive tool for the study of nitric oxide stress in *E. coli*. It also demonstrates an approach that can be translated to other organisms and conditions and ultimately aid in the rational design of therapeutics. His work was recently published in PLoS Computational Biology.

JESSICA SHANG
MECHANICAL AND AEROSPACE ENGINEERING

Hometown: **Silver Spring, Maryland**
Previous institution: **Harvard University**
Shang is investigating the potential of highly water-repelling surfaces (superhydrophobic) to reduce drag in smooth and turbulent flows. Shipping and aerospace industries consume billions of barrels of oil annually, a large fraction of which is needed to overcome drag. Even a small decrease in drag would lead to global energy savings. Conventional superhydrophobic surfaces, which use entrapped air, have shown promise but are not robust in many practical applications, such as high speeds. Seeking an alternative, Shang is studying a liquid-infused superhydrophobic surface, inspired by pitcher plants, which is hoped to retain drag-reducing properties under adverse conditions. Shang ultimately aims to discover governing properties of the surface treatment to improve drag reduction across a wide range of flow configurations.

AMY WU
ELECTRICAL ENGINEERING

Hometown: **Hsin-Chu City, Taiwan;**
Previous institution: **National Taiwan University**
Wu is studying how cancer becomes resistant to chemotherapy based on variations in genetics and the microenvironment surrounding the cancer cells. She has created microscopic structures to mimic the tumor microenvironment with a non-uniform drug distribution, and discovered that chemotherapy resistance of multiple myeloma rapidly emerged in such an environment. She then performed RNA sequencing of the resistant cells and discovered how new mutations and never-mutated genomic regions contribute to the drug resistance. Wu also models the interaction between cancer and non-cancer cells using evolutionary game theory. Her proposal for exploring how cancer cells may accept DNA from neighboring cells to construct a more heterogeneous genome received the Young Investigator Award from the National Cancer Institute.

CHEMICAL ENGINEERS TAKE ON COLLEGE PRESIDENCIES

Two Princeton Engineering alumnae have recently been appointed presidents of colleges, in both cases the first women to lead those institutions.

Rebecca Weiss Bergman assumed the presidency of Gustavus Adolphus College, in St. Peter, Minnesota, on July 1.

Previously, she had a 26-year career at the medical device company Medtronic, where she was vice president of research, technology and therapy delivery systems for the company's Cardiac Rhythm Disease Management business. She had served on the Adolphus board of trustees since 2007.

Bergman received her bachelor's degree in chemical engineering from Princeton in 1978 and went on to earn a Ph.D. at the University of Minnesota. She was elected to the National Academy of Engineering in 2010.

Alice Gast has been named president of Imperial College London as of September. She has been president of Lehigh University since 2006, and previously was vice president for research and associate provost at the Massachusetts Institute of Technology.

Gast earned her Ph.D. in chemical engineering from Princeton in 1984. She has been a member of the National Academy of Engineering since 2001.

ALUMNI TAKE ON LEADERSHIP POSITIONS

Gregory Adams was appointed COO of the state of Tennessee to oversee the operating efficiency of state departments. Prior to his new role, Adams was at IBM for 37 years, serving in management positions. Adams received an undergraduate degree from Princeton in 1976 in basic engineering.

Udit Batra was promoted to CEO and president at Merck Millipore, the life science division of Merck. He is also the chair of the food supplements committee of the Association of the European Self-Medication Industry and a member of the World Self-Medication Industry. Batra earned a Ph.D. in chemical engineering from Princeton in 1996.

Laura Bowles moved from Citibank to become CFO of Movement Mortgage, a rapidly growing purchase-mortgage bank founded in 2008. Bowles received a BSE in civil engineering from Princeton in 1997.

George Chesakov was named the new chairman-CEO of OAO OTP Bank, a financial institution with a strong presence in Russia and its parent bank in Hungary. Chesakov received an M.A. in computer science from Princeton University in 1999.

President Barak Obama appointed **Christopher Hart** as chair of the National Transportation Safety Board. Hart, whose appointment requires approval by the U.S. Senate, has been the board's acting chair. Hart earned BSE and MSE degrees in mechanical and aerospace engineering at Princeton in 1969 and 1971.

TransCentra, a provider of billing and payment software services for consumer and business-to-business markets, announced **Michael McCloskey** joined the company as CFO. He moves from CFO at Parkmobile USA Inc. McCloskey graduated from Princeton in 1992 with a BSE in civil engineering and operations research.

Jerald Murphy was appointed CEO of ACBB-BITS LLC, a subsidiary of Atlantic Community Bankers Bank. Previously, he was at Cognizant Technology Solutions Corporation. Murphy earned an MSE in electrical engineering from Princeton in 1993.

ALUMNI SERVE AS TRUSTEES AND BOARD MEMBERS

Harvey Bernstein, vice president of McGraw Hill Construction, Industry & Alliances, who received an MSE in civil engineering from Princeton in 1968, joined the corporate advisory board of the World Green Building Council.

James Famiglietti, a professor of earth system science and civil engineering at University of California-Irvine, who earned a Ph.D. in civil engineering and operations research from Princeton in 1992, was appointed to the Santa Ana Regional Water Quality Control Board by California Governor Jerry Brown.

Jonathan Huberman, president and CEO of Tiburon Inc. and Princeton alumnus with an A.B. in electrical engineering and computer science in 1988, was named to the International Association of Chiefs of Police Foundation board of directors.

CEO of BusinessExcelleration and partner at Tandem Capital **Beatriz Infante**, who has a BSE in electrical engineering from Princeton in 1976, was elected to the Liquidity Services board of directors.

Lisa Jackson, who earned a master's degree in chemical engineering from Princeton in 1986 and is currently vice president of environmental initiatives at Apple, joined the boards of trustees at Princeton and Tulane universities.

Former Vudu CEO **Mark Jung**, Class of 1982 with a BSE in electrical engineering, was named executive chair of OnLive.

John McDonnell, former chair of McDonnell Douglas Corporation and Princeton graduate with a BSE in 1960 and MSE in 1962 in aeronautical engineering, was elected chair of the Donald Danforth Plant Science Center.

Kimberly Ritrievi, president of the Ritrievi Group LLC and 1980 undergraduate alumna from chemical engineering, became a member of the Tetra Tech board of directors.

Eric Schmidt, executive chairman of Google and recipient of a BSE in electrical engineering from Princeton in 1976, was elected to the Mayo Clinic board of trustees.

Carl Sparks, former president and CEO of Travelocity and recipient of a BSE in mechanical and aerospace engineering from Princeton in 1989, was named to Dunkin' Brands board of directors.


The BLUE DOT
by Frank Espinosa & Sajan Saini
OUR ANCESTORS SOUGHT HUMAN-LIKE GODS AND PERSONAL DESTINIES IN THE NIGHT SKY, STRAINING TO BEHOLD MEANING WITHIN ITS COSMIC STARLIGHT.
WITH TELESCOPES, WE MASTERED NEW WAYS OF SEEING AND KNOWING, TO LEARN OF THE GREATER LIFE AND DEATH OF GASEOUS STARS.
BUT EVERY TOOL HAS ITS LIMITS!
WE'VE LEARNED THAT DISTANT STARS HAVE PLANETS TOO, BUT EVEN SPACE TELESCOPES HAVE YET TO SEE THESE NEW WORLDS...
THE GREAT DIAMETER OF OUR TELESCOPES ALLOWS US TO COLLECT FAINT LIGHT REFLECTED FROM FAR-OFF EXOPLANETS, AND THEIR GLOWING STARS.
LIGHT-YEARS AWAY, PLANETS AND STARS ARE POINTS OF LIGHT, TUCKED TOGETHER. BUT OUR LARGE TELESCOPES SHOULD STILL RESOLVE THEM.
LET'S TAKE A LOOK!
WHAT'S THIS? WHAT ARE THESE... RIPPLES?
WHERE'S THE EXOPLANET?
BUT, WE BUILT IT SO WIDE...!
RESOLUTION DOESN'T SEEM TO BE THE CRITICAL CHALLENGE. IS IT, CONTRAST?
INDEED! AS WAVES OF LIGHT SQUEEZE INTO A TELESCOPE...
THEY INTERFERE AND SMEAR A STAR'S BRIGHT IMAGE INTO RIPPLES THAT MASK DIM EXOPLANETS.
CAN WE ALTER OUR TELESCOPES TO ACHIEVE BETTER CONTRAST?
BELL LABS, MURRAY HILL. 1965.
PERHAPS... MATHEMATICIAN DAVID SLEPIAN MODELED HOW FILTERS IN TELESCOPE LENSES CHANGE THE INTERFERENCE PATTERNS OF LIGHT WAVES.
THE CONTRAST BETWEEN POINT IMAGES COULD BE MANIPULATED, IN PRINCIPLE...
PRINCETON UNIVERSITY: PRESENT DAY.
PROFESSORS JEREMY KASDIN, DAVID SPERGEL, AND ROBERT VANDERBEI RETHINK THE TELESCOPE'S PRIMARY MERIT OF COLLECTING AS MUCH LIGHT AS POSSIBLE, BY INSERTING A CORONAGRAPH MASK.
SLEPIAN'S MODEL WAS THE KEY!!
SHAPING THE SLIT, BASED ON SLEPIAN'S FUNCTION, WILL OPTIMALLY SUPPRESS SOME OF THE OPTICAL RIPPLES.
IF WE PARTLY MASK A TELESCOPE, WE LOSE SOME LIGHT... BUT WE CAN MANIPULATE WHAT TRANSMITS THROUGH A SHAPED SLIT.
...AND IF WE DESIGN A SERIES OF SLITS ACROSS THE MASK, WE'LL SUPPRESS MORE OF THE RIPPLE, AND DARKEN IT JUST ENOUGH...
THIS IS GOING TO HELP US SEE AN EXOPLANET?!!
IT IS AN UNUSUAL MASK SHAPE, I AGREE... BUT, LET'S TAKE A LOOK!
IT WORKS!
THE MASK SUPPRESSES A GOOD CHUNK OF THE RIPPLES!
... AND RECOVERS THE DARK. VOILA! THERE'S OUR EXOPLANET!
THE CORONAGRAPH MASK IS NOW A LEADING PROPOSAL FOR A NASA SPACE TELESCOPE TO OBSERVE EXOPLANETS.
HOWEVER, CHALLENGES REMAIN!
THE HARSH ENVIRONMENT OF SPACE ADDS VIBRATIONS AND TEMPERATURE EXTREMES THAT SLIGHTLY CHANGE THE SHAPE OF MASKS AND LENSES, DISTORTING THE IMAGE.
THE PRINCETON TEAM IS COLLABORATING ON WAYS TO FIX THESE PROBLEMS USING SMALL DEFORMABLE MIRRORS CONTROLLED BY COMPUTERS.
LIKE A FUNHOUSE MIRROR, THESE MOVING OPTICS CONTINUOUSLY SHIFT THE DISTORTED LIGHT AND RETAIN A STABLE REGION OF DARKNESS AROUND THE STAR!
DESPITE THE CLEVER MATH AND FINE COMPUTING, THERE'S NO IDEAL EXOPLANET IMAGING. YET, BY COLLABORATING WITH A COMMUNITY OF SCIENTISTS ACROSS HISTORY AND MANY NATIONS, RESEARCHERS ARE REALIZING STRATEGIES TO BRIEFLY GLIMPSE THESE HIDDEN WORLDS.
THESE NEW WAYS OF SEEING BRING US CLOSER TO THE ORIGINAL VISIONS OF OUR ANCESTORS THAN AT ANY PRIOR MOMENT IN HUMAN HISTORY.
BEYOND OUR EARTH, THE NEW TELESCOPES OF TOMORROW WILL BE POISED TO DISCOVER A TINY BLUE DOT, AND A VERSION OF OURSELVES, IN THE FAR-OFF DARK.