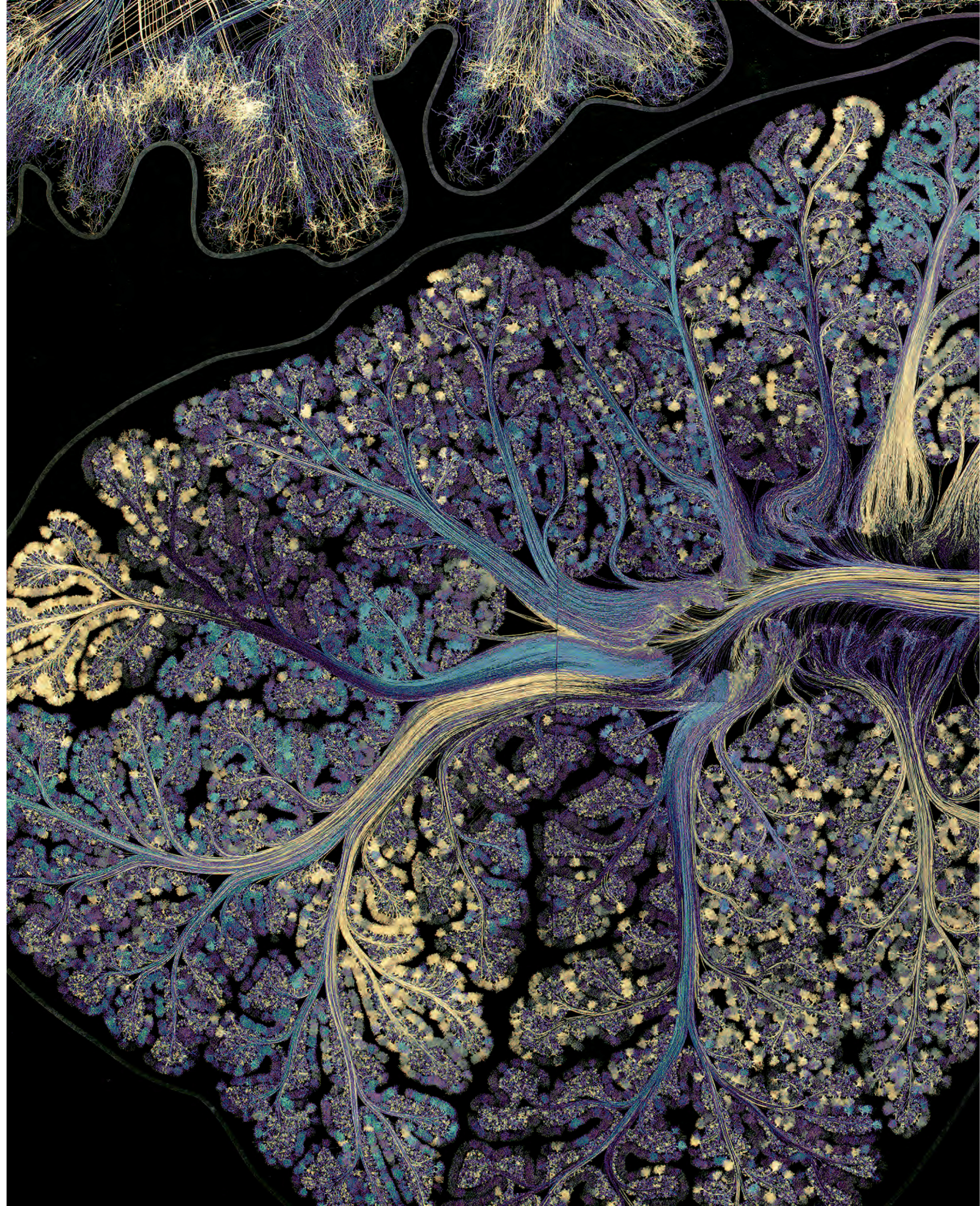




Penn Engineering



Networked Medical Devices





Self Reflected

On display at The Franklin Institute in Philadelphia, *Self Reflected* is the brainchild of Penn alums Greg Dunn (NGG'11) and Brian Edwards (ESE'08). Made of 25 etched plates hand gilded with 1,750 sheets of 22 karat gold leaf, the 12-by-8-foot piece depicts the circuit dynamics of approximately half a million neurons in the human brain.

Self Reflected, in Dunn's words, "was created not to simplify the brain's functionality for easier consumption, but to depict it as close to its native complexity as possible so that the viewer comes away with a visceral and emotional understanding of its beauty. Though the neuroscience of the piece was painstakingly researched to give the piece a level of reality not seen on this scale before, its deeper meaning is to elevate the consciousness of the average person to the exquisite machine that most defines our humanity."

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University of Pennsylvania
School of Engineering and Applied Science

“THE ‘INTERNET OF THINGS’
REVOLUTION WILL CONNECT
SENSORS TO THE PHYSICAL WORLD
AND WILL TRIGGER TREMENDOUS
ACADEMIC, INDUSTRIAL AND
CORPORATE IMPACT.”

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VIJAY KUMAR
Nemirovsky Family Dean

Engineering Health

The biggest challenges of healthcare, including finding cures for diseases, inventing novel therapeutics, fighting the next pandemic or making hospitals safer and more cost effective, will require collaborations between engineers, scientists and clinicians.

To meet these challenges, Penn Engineering is forging vital interdisciplinary collaborations, most notably in establishing key partnerships with the Perelman School of Medicine. One of our most spectacular new joint hires is Konrad Kording, a Penn Integrates Knowledge (PIK) University Professor with appointments in Bioengineering and Neuroscience. Kording’s interdisciplinary work uses data science to not only understand the human brain but also to help engineers design prosthetics and robots that can be driven by the brain. Kording and four other new hires over the past year have allowed us to nucleate new directions of research and education at the intersection of engineering and medicine.

The newly formed Penn Health-Tech, a Center for Health, Devices and Technology, unites the

University’s strengths in engineering, medicine and business to create technologies that address the world’s most pressing healthcare needs. Penn Health-Tech is co-directed by Insup Lee, Cecilia Fitler Moore Professor in Computer and Information Science, whose research focus has been on cyber-physical systems in medicine and transportation, where safety-critical software drives new functionality and efficiency.

Together, Penn Health-Tech, the Center for Engineering Mechanobiology, supported by a \$24 million grant from the National Science Foundation, and a \$9.25 million initiative funded by the Allen Foundation that will fund the study of the underlying mechanisms of concussions, all represent novel examples of collaborations in engineering human health.

Penn Engineering uniquely possesses both the campus infrastructure and the interdisciplinary culture necessary to create and sustain such collaborations. I am proud to be part of a school that is innovating to help improve human health. ♥

Inventing the Interconnected Future

Anesthesiologists carefully monitor an infant during surgery to assure she receives a steady flow of oxygen. Yet should anything go awry, by the time the pulse oximeter on her finger indicates a falling oxygen level, she may already be in danger.

To develop a more protective earlier warning system, engineers with Penn Research in Embedded Computing and Integrated Systems Engineering (PRECISE) worked with clinicians to detect and use diagnostic clues in multiple sources of streaming physiological operating room data. “We focus on the life- and safety-critical medical, transportation and energy sectors, the ‘cyber-physical systems’ comprised of sensors, computation, control and communication that are tightly integrated with the physical world,” says Insup Lee, director of PRECISE and Cecilia Fitler Moore Professor in Computer and Information Science.

REAL-WORLD IMPACT ABOUNDS AT PRECISE, A HUB OF THEORETICAL AND APPLIED RESEARCH BY NINE PENN ENGINEERING FACULTY MEMBERS.

Infant operating room data has been used to develop a prototype predictive device for hypoxemia, an abnormally low concentration of blood oxygen. “Clinicians will be able to use this device to find predictive patterns for when a surgical patient of any age is at risk for hypoxemia so they can intervene earlier to prevent problems,” says Allan Simpao, an attending anesthesiologist at Children’s Hospital of Philadelphia. “The PRECISE team is fantastic at what they do and at interfacing with clinicians.”

Real-world impact like this abounds at PRECISE, a hub of theoretical and applied research by nine Penn Engineering faculty members who work across disciplines to advance solutions to urgent challenges and opportunities as the world shifts to sensor-based technologies. They lead \$4 million per year in funded research and have pioneered new course and degree offerings that attract and cultivate next-generation leaders for a more connected and sensor-infused future.

SAFETY-CRITICAL INTEGRATION

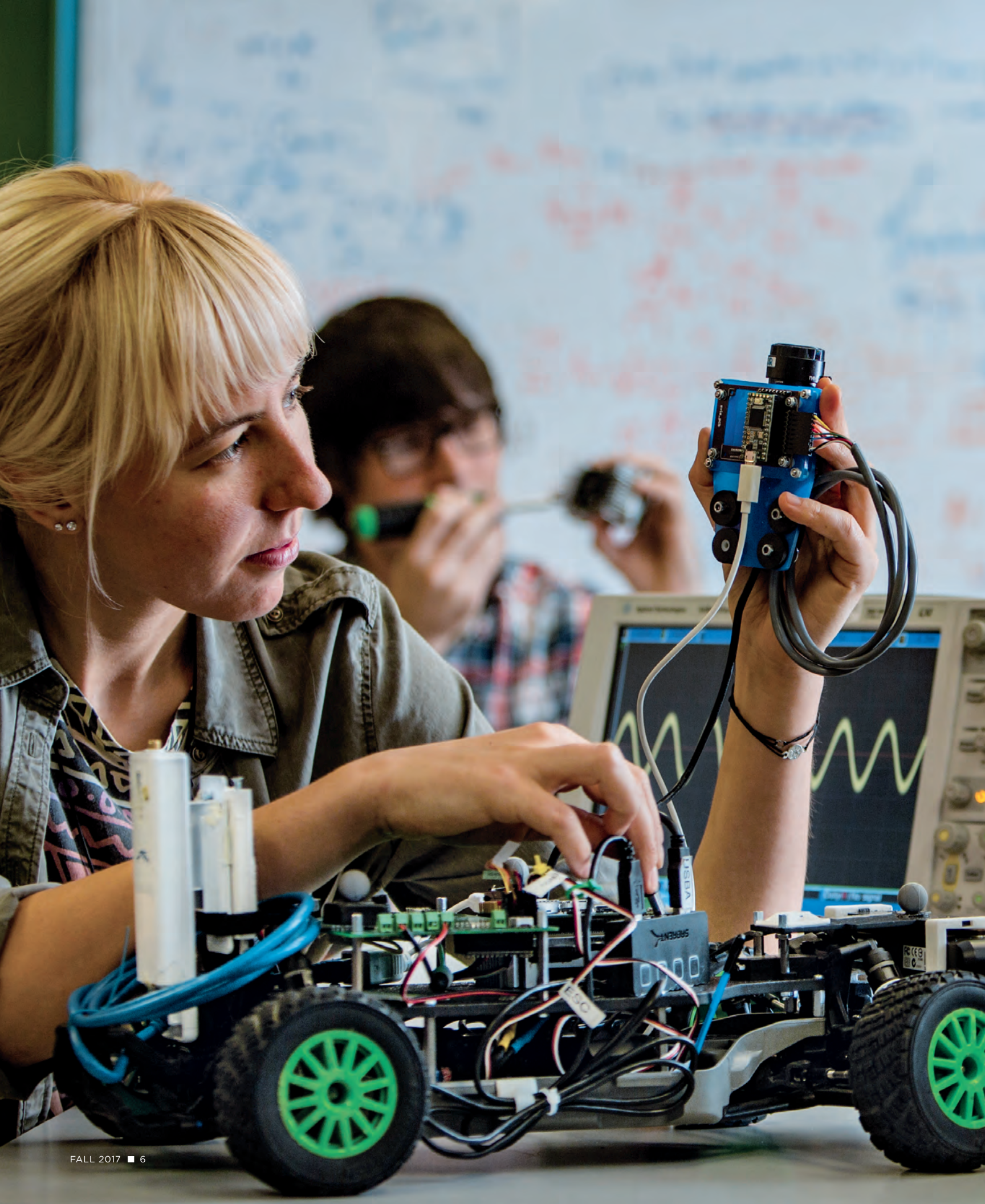
Sensor-driven phenomena such as the internet of things (IoT) are not about a specific technology. Instead, IoT refers to the sensor-embedded household, industrial, medical and commercial devices that are increasingly being designed to communicate and coordinate virtually.

“PRECISE is at the forefront of research to make devices connect and integrate seamlessly while always considering the risk aspect—to ensure safety, security, privacy and real-time performance,” says Lee. “For instance, we’re developing techniques to help self-driving cars withstand ‘spoofing’ attacks that send counterfeit signals to a vehicle’s navigation system.”

George Pappas, Joseph Moore Professor and chair of Electrical and Systems Engineering (ESE), describes sensor-based phenomena like the internet of things as the latest technology revolution. “IoT will have widespread academic, industrial and corporate impact because it’s so big, but nobody has access to the full stack of that vision yet. The real breakthroughs over the next decade will occur if someone creates an operating system that allows us to program across many heterogeneous devices,” he states.



Research Assistant Professor James Weimer, Professor Insup Lee and doctoral student Ramneet Kaur set up a patient simulator to experiment with medical device interoperability.



Doctoral students Alena Rodionova and Matthew O’Kelly are developing the Formula 1/10 autonomous race car’s sensor fusion module, part of the driver’s license test for the Safe Autonomous Vehicles project.

“This is an exciting time to go into this field,” concurs Linh Thi Xuan Phan, assistant professor in Computer and Information Science, who works on methods to defend interconnected devices against attacks, bugs and intrusions, and ways to assure that interconnected devices like cars and cardiac monitors maintain life-saving responsiveness. “It’s inspiring to invent solutions to shape a more safe and secure future.”

GRAND THEFT (VIRTUAL) AUTO

As he reviews real footage of fatal autonomous car crashes and describes the absence of a comprehensive regulatory framework, it’s clear there’s a need for the research conducted by Rahul Mangharam, associate professor in ESE. “We use simulated hyper-realistic environments with high fidelity physics to test drive real autonomous vehicle software and investigate how the vehicle behaves in accident and near-accident situations,” he says. Mangharam connects data from autonomous cars to an adapted version of the video game *Grand Theft Auto* to test how autonomous cars respond to high-risk driving scenarios and improve vehicle perception, planning and decision control.

Mangharam’s research collaborations focus on the technological, legal and ethical design of safe autonomous systems (such as how to develop driver’s license tests and insurance coverage for autonomous vehicles), strategies to manage energy consumption during volatile energy markets and weather patterns (with National Science Foundation (NSF) funding for commercialization of this approach), and medical topics such as integrating operating room device data to convey the fusion of factors affecting patients.

David Corman, Cyber-Physical Systems program director in the Computer and Information Science and Engineering Directorate at the NSF, says, “We would bet our lives on many of the devices PRECISE has worked on. Some of the areas of research they’ve engaged in are

really new methods to verify that criticality. The PRECISE center is among the leaders setting this research agenda.”

CURRICULAR INNOVATIONS

“PRECISE is also among the groups that helped shape novel and innovative educational curricula in the area of IoT and cyber-physical systems,” Corman continues. “The students from their program have gone on to become some of the great investigators in this field.”

The Center is a hub for 15 postdoctoral fellows, 45 doctoral candidates, 40 master’s students and a growing number of undergraduates. Integrative degrees reflect how the program has anticipated the skills needed for this emerging field. In 2009, Penn began offering a master’s in Embedded Systems, one of the world’s first IoT-related educational degrees. A new IoT concentration for undergraduates is being developed in ESE and will be available beginning in 2018-2019, and an online micro-master’s IoT degree (via edX.org) is being developed and will likely launch in 2018. Pioneering IoT course offerings are growing as well, such as Embedded Software for Life-Critical Applications; Digital Twins: Model-based Embedded Systems; and The Security of the Internet of Things, which is the first on this topic at any university.

“While our curriculum reform is never complete, we are way ahead of the competition in educating 21st century engineers for IoT,” continues Pappas. “We’re preparing our students to be innovators and participants in the enormous startup opportunities in the IoT space.”

Striking a note of cautious optimism, Mangharam adds, “We’re mentoring the coming generation of engineering citizens who will develop these large-scale autonomous systems. These will soon become integrated into our lives in ways that we cannot take lightly, and the burden is on us to make sure these systems are safe and have a positive impact.” 🍓

By Jessica Stein Diamond



Professor Paulo E. Arratia (left) and Wellness Committee Liaison Michaile Rainey (far right) talk with a student on Smith Walk.

Staying on Track

Advancing Student Wellness

At a school like the University of Pennsylvania, expectations for success run high. It can be easy for students, when faced with their cohort of exceptional peers, to have moments of self-doubt. Mix in stressful life events, being away from home and heap on social media hype that can make others' lives look ideal, and you have a perfect opportunity for anxiety that can quickly derail a student's progress.

"Illness, relationship changes, financial issues or emotional conflicts are part of life. One aspect of the university experience is learning to manage those conflicts and the stress that goes with it," says Dr. Sonya Gwak, director of Student Life at Penn Engineering. "But when a student is unsure of how to talk about the problem, or ignores it, stress can quickly turn to distress, which can interfere with academic performance."

For some students, a natural inclination can be to put on a positive face and work harder in the pursuit of perfection, rather than dealing with stress or recognizing the signs of depression. The University of Pennsylvania met these factors head-on by developing its Wellness Ambassadors Program, which began after a request from the Penn Faculty Senate. This program trains University faculty to serve as liaisons to their fellow faculty members, and the program is currently being piloted in the four undergraduate schools (the College, Engineering, Nursing and Wharton). Each school adopts its own approach to using Wellness Ambassadors, but all Ambassadors work to promote an awareness and understanding of student wellness.

"Penn has always taken a holistic approach to student success. The Wellness Committees in the

four undergraduate schools provide a structured process for how to reach out to students in distress and help match them with appropriate support services," says Gwak, who is also a Wellness Committee member. "At Penn Engineering, we've taken the Wellness Committee concept further by formalizing a collaborative team of faculty and staff who focus on student wellbeing."

PENN ENGINEERING'S WELLNESS PROTOCOL IS STRUCTURED TO EFFICIENTLY CONNECT STUDENTS WITH RESOURCES AHEAD OF A CRISIS AND HELP THEM REGAIN BALANCE.

At the school level, Penn Engineering has developed a unique protocol through its Wellness Committee, which consists of the faculty Wellness Ambassadors as well as staff Wellness Liaisons in the Office of Research and Academic Services (RAS). These individuals are academic advising staff members assigned to specific departments. Penn Engineering's protocol is structured to efficiently connect students with appropriate resources ahead of a crisis and help them regain balance and stay on track.

STARTING CONVERSATIONS

Identifying a student who is exhibiting distress is not difficult for Penn faculty. Between classroom time and office hours, they are often able to observe the telltale signs that indicate a student isn't handling a challenge well. "Our faculty are wholly engaged in student success, pay attention to their students and

are willing to help,” says Michaile Rainey, Wellness Committee Liaison and director of Advancing Women in Engineering at Penn Engineering. “We found that they wanted to know how to appropriately engage with students about their observations and get them the help they need. That’s where our faculty Wellness Ambassadors come in.”

There are six Wellness Ambassadors on the Penn Engineering Wellness Committee, representing each academic department. They take part in a rigorous seven-hour training program with Penn’s Counseling and Psychological Services (CAPS) to learn how to be effective liaisons between the faculty and the Wellness Committee. “As Wellness Ambassadors, we make sure our fellow faculty members are aware of all of the resources available to help students,” explains Paulo Arratia, professor and associate chair for Undergraduate Affairs in Mechanical Engineering and Applied Mechanics (MEAM). “We are their resource when they think they have identified a student who is struggling and want support in talking to that student. We also interface with other Wellness Committee members who are skilled in doing outreach to students.”

Arratia has a deeply personal reason for adding his Wellness Ambassador responsibility to an already extensive academic schedule. “I have dealt with depression and anxiety and I know the importance of seeking help,” says Arratia. “I was lucky that someone saw those signs and helped me find the help I needed. I want my students to see that even though you have a battle, you can still do well.”

IDENTIFYING RESOURCES

Faculty play a much larger part in student wellness than previously imagined. “If a friend suggests another student talk about a problem or take advantage of support services, it’s not likely the student will follow through,” says Arratia. “But we have found that if a faculty member reaches out, the student is more likely to follow through in seeking help.”

The goal of that first conversation between a faculty member and student isn’t counseling. Rather, it lets the student know someone cares about their success and encourages the next step in the process. “During that conversation, the faculty member will typically suggest a Penn Engineering Wellness Committee Liaison in RAS as a resource for help. If the student is agreeable, the faculty member will let the student know that the Liaison will contact that student to follow up,” says Rainey.

“AS WELLNESS AMBASSADORS, WE MAKE SURE OUR FELLOW FACULTY MEMBERS ARE AWARE OF ALL OF THE RESOURCES AVAILABLE TO HELP STUDENTS.”

Penn Engineering Wellness Committee Liaisons have deep insight into student support services at Penn—everything from academic help and skill development to financial aid, mental health support and primary care. “Because we are deeply engaged in student life here, we can quickly match a student with a staff member who can help them manage their problem and be a successful student,” says Gwak. For instance, if a student athlete is struggling with a problem, a Wellness Committee Liaison who manages athletic eligibility would be able to relate well to the student, direct them to the right services and support them on their journey in resolving the problem.

“You can’t just give a student who has a problem information and send them on their way,” says Rainey. “They need follow-up and a gentle push to move forward. This committee provides the scaffolding that will strengthen a student, and help them to develop the soft skills that will equip them to be leaders and citizens who are creative innovators and developers who do good in the world.” 🍓

By Amy Bremiller

Self Reflected

Bringing the Conscious Brain to Life



Greg Dunn and Brian Edwards discuss the intersection between art and science in Self Reflected, an animated depiction of what happens inside your brain when you observe art.

If you're lucky enough to wander into the *Your Brain* exhibit at The Franklin Institute in Philadelphia, you're in for a mesmerizing treat—a portrait of the brain, ironically, as it views a work of art. The stunning display, appropriately called *Self Reflected*, depicts a thin slice of the human brain scaled up by a factor of 22. Made of 25 etched plates hand gilded with 1,750 sheets of 22 karat gold leaf, the 12-by-8-foot piece depicts the circuit dynamics of approximately half a million neurons. A network of 144 LED spotlights flash across the piece to give it its life, yielding 500-microsecond animations of brain activity that unfold in colorful waves as the viewer walks from one side to the other.

Self Reflected is the brainchild of full-time artist Greg Dunn (NGG'11) and Brian Edwards (ESE'08), who now works as a research scientist in the lab of his former doctoral advisor Nader Engheta, H. Nedwill Ramsey Professor in Electrical and Systems Engineering.

With the help of about half a dozen Penn undergraduate students, the duo spent two years creating the world's most complex piece of art on the brain to bridge the gap between the large-scale view of the brain and the activity of individual neurons, thereby elucidating the nature of human consciousness.



As Edwards explains, this ambitious endeavor presented a unique challenge. “Most systems, from clocks to computer chips, can be easily reduced to the sum of the components. However, you can understand each individual neuron in the brain and not understand how the magic of consciousness appears out of them,” he says. “Borrowing the adage of ‘missing the forest for the trees,’ we wanted to present both the forest and the trees in as much detail as we could. If you get close enough, you can see individual dendrites, but if you stand back, you can see brain waves and flashes of regional activity.”

CHOREOGRAPHY OF NEURAL ACTIVITY

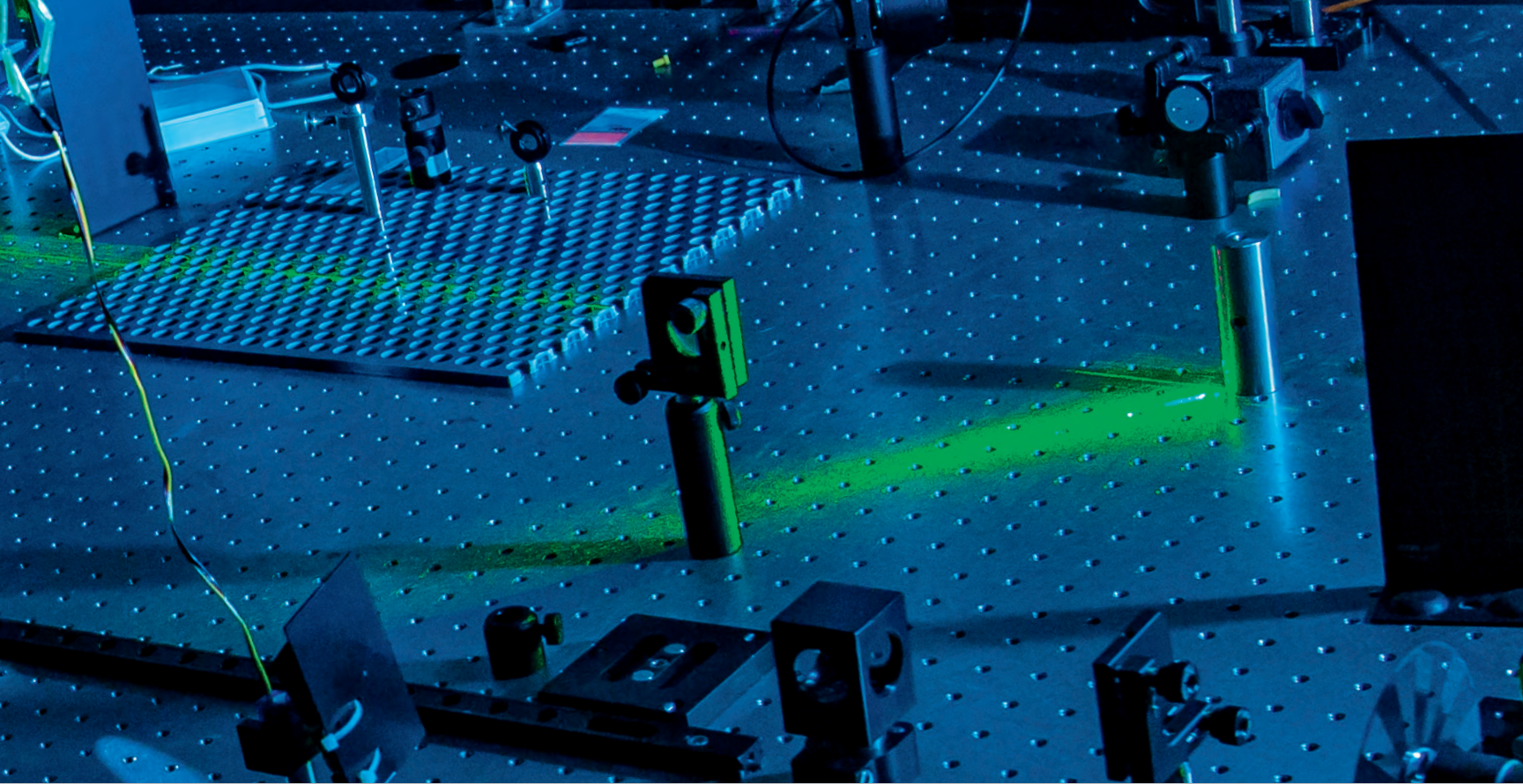
The secret to success behind *Self Reflected* was reflective microetching, a technique invented by Dunn and Edwards to microscopically manipulate the reflectivity of a surface. This creates a third dimension of information based on the angle of reflectivity, which can be used to create animations on a seemingly two-dimensional surface. Their approach combines hand drawing, scientific data, computer simulation, photolithography, gilding and strategic lighting design.

Microetchings are comprised of collections of angled ridges that are designed to gather light from a source at one location and reflect it to an observer at another location. Through smooth and subtle changes in the angles of the ridges, microetchings become animated as either the light source or the observer moves. Even though *Self Reflected* is a single piece of art, the microetching can appear in a huge number of ways depending on how it is illuminated and where the viewer is standing.

ROOTS OF *SELF REFLECTED*

Before creating *Self Reflected*, Dunn and Edwards began by working on microetchings of small numbers of neurons. After earning a Ph.D. in Neuroscience from Penn in 2011, Dunn became a full-time artist and was invited to give an art show at the National Science Foundation (NSF) headquarters in Washington, D.C. Based on these early microetchings, the NSF invited the duo to give an informal talk, and subsequently, to submit a proposal.

Their efforts paid off. In 2014, they received the NSF's Early-concept Grants for Exploratory Research (EAGER) award, sponsored by Penn, for



Brian Edwards performs laser alignment on an interferometer to determine the coherence length of a laser.

the creation of the most comprehensive illustration of the human brain ever produced. Three years later, *Self Reflected* was named Expert's Choice for illustration by the NSF and *Popular Science* magazine in the 15th annual Vizzies Challenge, which celebrates the use of visual media to artfully and clearly communicate scientific data and research.

**THE SECRET TO SUCCESS BEHIND
SELF REFLECTED WAS REFLECTIVE
MICROETCHING, A TECHNIQUE
INVENTED BY DUNN AND EDWARDS
TO MICROSCOPICALLY MANIPULATE
THE REFLECTIVITY OF A SURFACE.**

"The NSF cares deeply about science education and outreach," Edwards said. "They felt that *Self Reflected* had the ability to communicate something about science that couldn't be conveyed through traditional means such as textbooks. We are very grateful to them for believing in this idea."

Dunn and Edwards also credit their respective Penn educations for their success. For example, Edwards has taken a wide range of courses in optics, electrical engineering and computer science. He has also made use of lab space generously offered by Engheta. As a graduate student and now as a research scientist in the lab, where research focuses on the physics and engineering of fields and waves and the various features and characteristics of wave-matter interactions, Edwards has gained extensive experience running optical, radio-frequency and microfluidics experiments.

This broad-based training allowed Edwards to tackle the greatest challenge of *Self Reflected*, writing specialized computer algorithms that produced an animated neural network, in addition to developing lithographic exposure systems and a sophisticated lighting system to help bring the piece to life. "Penn is very encouraging of mixing ideas and skills across disciplinary boundaries," Edwards said. "It is only within the incredibly supportive environment of Penn that we could have undertaken a project of this magnitude." 🍷

By Janelle Weaver



Vivek Shenoy

Vivek Shenoy

Mathematical Models for the Mechanical Body

While they can seem imperfect on the surface, our bodies are in fact finely tuned machines. Joint surfaces glide effortlessly across one another. Tendons and muscles work together to control our movements, letting us run laps, hold conversations, scarf down cheesesteaks and play piano. This complex collection of biological levers, springs and pulleys is enough to keep a mechanical engineer busy for decades.

Vivek Shenoy knows this firsthand. He isn't interested in just joints and tendons; instead he's homing in on microscopic structures within the body and wants to understand how they shape our tissues at a basic level. A professor of Materials Science and Engineering, with secondary appointments in Mechanical Engineering and Bioengineering, Shenoy is also the co-founder and director of the \$24 million NSF Science and Technology Center for Engineering Mechanobiology, where he aims to describe basic biological processes using mathematical tools.

From soft neurons to tough muscle, he notes, every cell contains a web of tiny filaments inside it. These strands, made of sugars called polysaccharides, support the cell's contents and give it a specific structure. Webs of similar filaments also exist outside of cells, binding them to one another and fusing them into larger tissues. The properties of these fibrous "scaffolds" determine the physical qualities of our tissue. If the strands are thin and loose, they'll make tissue that's flaccid; if they're tightly packed, it will be tough and firm. In addition to controlling a tissue's physical properties, however, these scaffolds may have a much deeper impact on cells. Shenoy believes they may even affect DNA.

STRETCHING CELLS

"Let's say a cell is suspended in a really stiff scaffold. That exerts a certain force on the entire cell, and squeezes its nucleus, which can in turn change how genes are expressed," Shenoy says. "Some genes

will be newly exposed, and so will be expressed more than usual. Others will be hidden, and will be expressed less frequently. You can effectively change the genetic function of a cell just by yanking on its nucleus."

Those changes go both ways, Shenoy notes. While the stiffness of a cell's scaffolding alters the genes expressed within it, some of those genes can in turn change the properties of the scaffold.

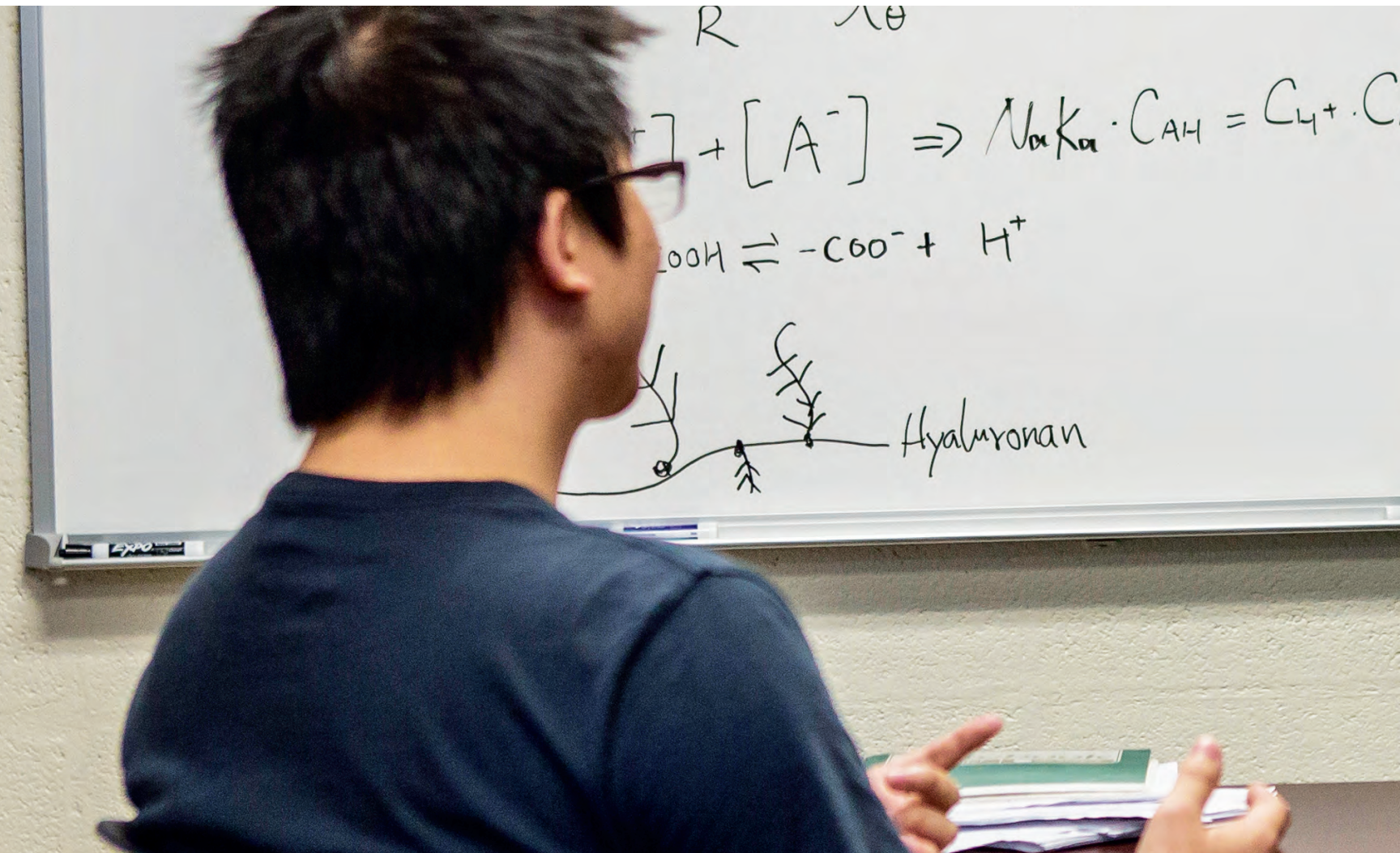
SHENOY IS HOMING IN ON MICROSCOPIC STRUCTURES WITHIN THE BODY AND WANTS TO UNDERSTAND HOW THEY SHAPE OUR TISSUES AT A BASIC LEVEL.

"It's a constant feedback between mechanics and chemistry," he says. "As stiffness or tension increases outside of a cell, it expresses genes that can then affect the tension of the cytoskeleton." If the cytoskeleton relaxes, the cell deforms, changing the tension of filaments connected to its exterior.

Think of it a bit like a beach ball suspended in the middle of a room. Long threads connect it to the floor, ceiling and walls. When the ball is fully inflated, all those threads have equal tension on them. But if the ball loses air, some of the strands go slack. The same interplay is at work within human tissue.

THE MECHANICS OF CANCER

This sort of physical-chemical feedback could have big implications for diseases like cancer. For a tumor cell to spread throughout the body, it has to work its way through a thicket of connective tissue, dive into blood vessels and plant its flag somewhere new. It's no small feat.



In his lab, however, Shenoy found one way that cancer cells get around this challenge. Instead of forcing their way through tough extracellular fibers, they simply change those fibers' properties. As the cells attach to each individual strand, they can break the links that hold the fibers together, weakening connective tissue. Like explorers trailblazing through dense jungle, they can then make their way through the resulting holes.

Shenoy tested this in the lab by creating a gel that simulated human tissue. Within 12 hours of seeding it with cancer cells, he says, its previously uniform density had totally changed. In some areas, it stayed firm and resilient, but in others, it softened dramatically, letting cancer cells spread at will.

LEARNING NEW DISCIPLINES

Currently, Shenoy and his lab are working on better understanding this process. If they can chip away at

the basic science behind it, he reasons, it might be possible to one day develop drugs that stop cancers from metastasizing in the first place.

It'll take more than just a mechanical engineering approach. Teasing out the connections between mechanics and biochemistry requires a number of different disciplines, including biology, medicine, engineering and physics. That's the impetus behind Penn's Center for Engineering Mechanobiology.

"The core mission of our Center is to expand the capability of graduate students and postdocs across the physical and biological sciences," says Jim McGonigle, managing director. "We have some students who are traditional biologists, with no engineering and little computational background, and others that are engineers with no experience with living cells and tissue. Our goal is to give them all the skills to interact in a meaningful way and learn from one another."



From left: Materials Science doctoral candidates Xingyu Chen and Chris Price discuss with Professor Shenoy how cells can remodel the extracellular matrix and how these changes can in turn affect cells' shape, stiffness and migration.

To that end, Shenoy hosts an annual “Boot Camp” for new students, where he starts to fill the holes in their knowledge.

“We start with the fundamentals, like understanding force and balance. Then, gradually, you add more and more mathematical concepts. Soon you start to realize that you can use them to write equations describing biological systems,” Shenoy says.

Shenoy and his team ultimately want to create mathematical models of biology on a few different microscopic scales, ranging from individual molecules and genes to entire tissues.

Right now, it’s an exercise in basic science, he says, but it could someday be used to engineer new tissue or build organs-on-chips, high-tech devices that let researchers predict how new drugs affect human tissues. The work could even help scientists to better understand how stem cells and embryos

form. But first, Shenoy states, he wants to change the way students think about the fledgling field.

TEASING OUT THE CONNECTIONS BETWEEN MECHANICS AND BIOCHEMISTRY REQUIRES A NUMBER OF DIFFERENT DISCIPLINES.

“It’s not limited to biology. I want to give students the tools to apply theory and mathematical concepts to any difficult problem. There are only so many concepts out there in the physical sciences, but the same concept can be applied in many different ways,” he says. “We’re always trying to solve puzzles from different areas. That’s the most attractive part of the job.”

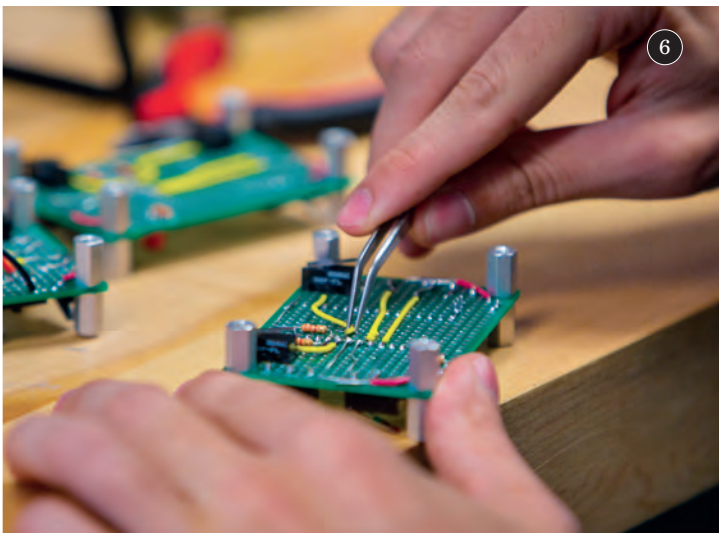
By David Levin



On Our Camera Roll



1. The quickest way from Skirkanich to Levine Hall on a rainy day is via the Quain Courtyard. **2.** Students demonstrate their custom-built plate reader to others in the Stephenson Foundation Undergraduate Laboratory. **3.** Research Assistant Manas Shukla reviews an algorithm for his Autonomous Air Traffic Control project. **4.** Junior Lauren Glenn face mills a piece of aluminum in the Mechanical Engineering machine shop. **5.** Senior Lecturer Thomas Farmer conducts office hours for advising, questions and discussion.



6. Diego Caporale, teaching assistant for Mechatronics, assembles a wireless controller. **7.** The Weiss Tech House is a student-run hub for technological innovation, providing collaborative space for projects. **8.** Bioengineers analyze pharmacokinetic data to understand drug delivery. **9.** Senior Selena Akay measures the buildup of electrical charge created by a static electricity pump in the Engheta Lab. **10.** Students discuss plans for an interdisciplinary Senior Design project in Bioengineering and Mechanical Engineering.

Play Hard, Work Harder

Taking it to the Edge on the Court and in the Classroom

From mid-August to late November, even as they face down the inevitable intellectual challenges of a new academic year, the women of Penn Volleyball practice their sport three hours a day, four days a week. Add to this their all-important Division I competitions, with many players spending additional hours on the road traveling to games out of state.

The arrival last spring of Katie Schumacher-Cawley, the University's new Kenneth L. Gross Head Coach of Volleyball, only served to turn the intensity up a notch. During their off season, players soon discovered what it takes to make it through the lightening-paced cardio-based drills, skill-honing workouts and weight-lifting sessions that define the strategy of their new coach. When team members were asked for their impressions of this novel training and conditioning regimen, the word "sweat" came up a lot. The significant demands can be met by only the most committed of student athletes.

JUST AS THESE WOMEN FEED OFF OF ONE ANOTHER'S PHYSICAL ENERGY ON THE COURT, THEY ALSO CREATE AND SHARE A STRONG INTELLECTUAL ENERGY.

Cue players Brooke Behrbaum, Carlie Bolling, Caroline Leng, Sydney Morton and Caroline Raquel, all devoted volleyball players and all Penn Engineers.

Behrbaum, a 6'2" middle blocker from Mercer Island, Washington, is a junior majoring in Systems Science and Engineering with a minor in Computer Science. Active in club team volleyball since she was 13, her love of the game is apparent. She is quick to make the point, however, that she does not "major in volleyball."



From left: Caroline Leng, Caroline Raquel, Brooke Behrbaum, Carlie Bolling and Sydney Morton.



THE ACADEMIC PATH

When visiting campus as a high school junior, Behrbaum, a National Merit Scholar, found it unique to Penn that, as a recruited athlete, she would be free to follow “the academic path” without expectations or encumbrances. This was key to her decision to enroll. Similarly, she finds her professors supportive of her time-intensive sports schedule. Last summer was the first in years that Behrbaum, an avid horsewoman, was not volunteering as a riding instructor. Instead, she spent her “vacation” as an Engineering Practicum Intern at Google, where she has been invited to return next year.

Freshman Caroline Leng, a 6’3” middle blocker from Poolesville, Maryland, began playing volleyball in seventh grade, but until her freshman year of high school, playing college sports was not on her radar. In high school, Leng lettered four times in volleyball, was a three-year captain, and her team was a state finalist her freshman year, going 18-1 and winning league, county and regional titles. When Leng started receiving interest from university coaches, she decided to pursue college athletics.

LAST YEAR’S ENTIRE TEAM OF 26 WAS RECOGNIZED BY THE AMERICAN VOLLEYBALL COACHES ASSOCIATION (AVCA) WITH A TEAM ACADEMIC AWARD.

With majors in Computer Engineering and Entrepreneurship Management, Leng is enrolled in the Jerome Fisher Program for Management and Technology (M&T). This newly minted Quaker was drawn to both engineering and business, and feels that M&T is a perfect fit for her. “Penn’s entrepreneurial ecosystem, as well as the creative and supportive environment, is perfect for an aspiring entrepreneur,” she says. Leng also finds time to be a member of Penn Electric Racing, the M&T Board, and a writer for *Unearthed*, a magazine dedicated to inspiring and educating children and teens in the West Philadelphia area.

Another Systems major, sophomore Carlie Bolling is a defensive specialist for the team. A multi-talented athlete from Sevierville, Tennessee, Bolling had been given the opportunity to take her talent

as an elite middle school gymnast to the national competitive level. Bolling instead decided to direct her formidable 5’1” energies into her studies and the game of volleyball. She graduated from high school as a four-year letterman and team captain, having distinguished herself as an AP Scholar with honors and class valedictorian.

EVERYTHING CAN BE OPTIMIZED

Bolling is a “natural problem solver” with an eye toward optimization (“Everything can be optimized!”). Wanting to push herself academically in high school, Bolling discovered the University of Tennessee’s Society of Women Engineers (SWE), through which she became inspired and encouraged to further pursue STEM-related courses.

Caroline Raquel, a 5’10” sophomore from Los Angeles, California, is an outside hitter for the team and is enrolled in the M&T program as well, majoring in Bioengineering and Finance. When looking at colleges, the excitement and vibe of an urban environment appealed to Raquel, and it was love at first sight when she stepped onto the Penn campus. She was especially intrigued to learn that all volleyball team members live together in off-campus houses; it is a tradition (along with the real estate) passed down over the years. To Raquel, living with her teammates not only translates into “more friends!” but also into a deeper commonality: “We’re all here for the education.”

Raquel remains passionate about Feed2Succeed, a nonprofit she founded with her sister, Carmina, and a high school friend. The sisters are second-generation Filipinos, and a trip to the birth country of their parents opened their eyes to the needs of malnourished children in the Philippines. Partnering with a civic organization in the city of Vigan, they continue to make a difference in the lives of impoverished families there.

Sydney Morton is a senior from Atlanta, Georgia, majoring in Computer Science. She has been the captain of the team for the past two years. The 5’10” setter has seen some serious playing time, competing in all 26 matches last season. Her impressive 2016 game statistics earned her an Honorable Mention All-Ivy along with Academic All-Ivy. (Last year’s entire team of 26, in fact, was recognized by the American Volleyball Coaches Association (AVCA) with a Team Academic Award.)



Penn's Division I Women's Volleyball team practices four days a week, with two games every weekend. Warm-ups (above) consist of drills such as peppering, which is played in pairs and works on ball control.

RIGOROUS REQUIREMENTS

As a varsity volleyball player, scheduling classes to meet the rigorous requirements of an engineering degree is challenging, and can make for some hectic moments. Morton recounts that in the fall semester of her junior year, her unofficial workout included a sprint from practice at the Palestra to a class in David Rittenhouse Laboratory. Having worked up a sweat during training drills before taking her classroom seat just under the buzzer, Morton was probably not a candidate for the best-dressed list.

A recruited athlete, Morton visited campus as a high school junior and was inspired by the team culture. She has since become immersed in it, living in the “senior house,” sharing meals and studying

with her teammates. She notes that just as these women feed off of one another's physical energy on the court, they also create and share a strong intellectual energy. After graduation, Morton will be working as a developer at Microsoft.

As a head coach getting to know the Penn Engineering members of her new team, Schumacher-Cawley, an All-American and NCAA champion as a player at Penn State, is clearly impressed with their energy, drive and clarity of purpose. Discussing the ease with which all of them seem to navigate their lives as student athletes, Schumacher-Cawley puts it succinctly: “They make it work.” 🏐

By Patricia Hutchings

Harjot Gill

Listening in on the Cloud

In recent years, in conjunction with the rise of social media and the internet of things (IoT), there has been tremendous growth in cloud computing. A powerful technology for hosting and delivering services over the internet, cloud computing reduces hardware maintenance expenses and overall operating costs for businesses. With this transformation comes a new set of problems: Few tools are available to adequately address the issues that accompany data processing in the cloud.

Every digital business is now powered by hundreds of services and thousands of service interactions in the cloud. Yet due to the distributed nature of the cloud, development and operations (DevOps) teams, which are responsible for uptime and performance of applications, cannot see these services and cannot see the service dependencies. This critical blindness incurs a huge financial cost from prolonged outages, bad deployments, and ineffective planning.

To overcome this problem, Harjot Gill (MSE'13) co-founded a company called Netsil, which delivers a cutting-edge monitoring solution for distributed cloud applications. The company offers a unique product that tracks and analyzes data in complex distributed systems, improving cloud application performance and allowing businesses to optimize their resources. Netsil's software provides insights into service delivery and user experience of cloud applications and helps troubleshoot performance bottlenecks.

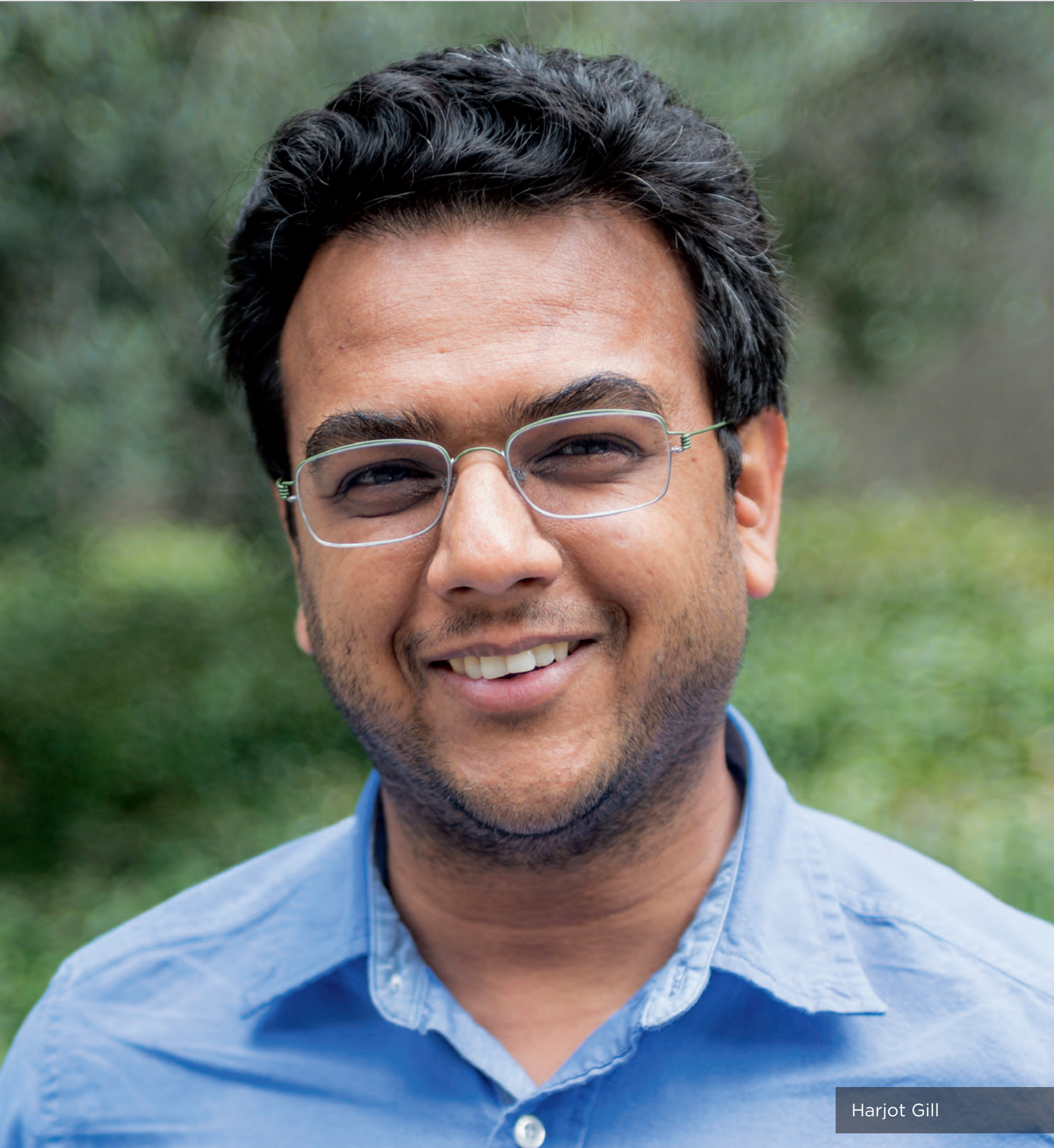
NETWORK-CENTRIC APPROACH

"When you consider the chaos in the application space with new programming languages, abstractions and frameworks, the network itself emerges as a natural, stable vantage point to observe and monitor modern cloud applications," Gill says. "Netsil's network-centric approach is future-proof across generations of applications."

NETSIL, WHICH IS "LISTEN" SPELLED BACKWARDS, DELIVERS A CUTTING-EDGE MONITORING SOLUTION FOR DISTRIBUTED CLOUD APPLICATIONS.

"Listen" spelled backwards, Netsil is based on a unique technology that provides real-time, non-intrusive monitoring of communications in cloud applications, similar to neuroimaging techniques such as positron emission tomography. "We use the data that we collect from the communication patterns we observe to build a map of cloud apps and find areas of congestion," Gill says. "It's a groundbreaking technology that allows us to understand the performance of cloud apps better than any other technique on the market."

Unveiled in September, Netsil's new Application Operations Center (AOC) is a universal observability and monitoring platform for modern cloud applications. With the AOC, Netsil now enables



Harjot Gill

DevOps teams to gain complete visibility into all of their services and dependencies using real-time maps, with absolutely no code changes required. As a result, the teams are able to reduce downtime, ensure safer deployments and meet their service level objectives.

NETSIL PRESENTS HUMAN OPERATORS AN INTERFACE THAT CAN BE THOUGHT OF AS A KIND OF ‘GOOGLE MAPS FOR CLOUD APPLICATIONS.’

This technology is invaluable for e-commerce. Businesses that sell goods online suffer revenue losses when their websites hang up and potential buyers abandon their shopping carts. Netsil overcomes this obstacle by discovering problems affecting the performance of cloud applications before they even occur. “Netsil presents human operators with an interface that can be thought of as a kind of ‘Google Maps for Cloud Applications,’ which helps speed up their job by orders of magnitude,” Gill says. “In industry, almost every enterprise is moving its workflow to the cloud, and the rise of the internet of things will only expand that workload in the next few years.”

SEEDS FOR SUCCESS

Netsil has its roots in the lab of Jonathan Smith, Olga and Alberico Pompa Professor of Engineering and Applied Science in Computer and Information Science (CIS). As a graduate student in the lab, whose long-term objective is to create useful distributed computing systems, Gill was working with his brother, Tanveer Gill (MSE’14), and undergraduate student Cam Nguyen (BSE’12) when the idea for Netsil began to emerge.

“We had a solution looking for a problem. It took a while to find a large enough problem in the market to address with our technology,” Gill says. “You can apply it in 10 different ways

to solve 1,000 different problems, and it’s hard to pick one problem in the enterprise software space. The greatest challenge was to decide what type of company we wanted to build from all of these options.”

Even at this early stage of development, their solution was promising enough to attract the attention of the National Science Foundation. With this funding, the Gill brothers and Nguyen rented out two tiny rooms a block away from the Penn campus and worked day and night to further develop their product.

Capitalizing on their hard work, the trio garnered a worldwide exclusive license from Penn and co-founded Netsil in 2012, along with Shariq Rizvi, who was a software engineer at Google and director of the performance ads team at Twitter. Thanks to the combined experience of the co-founders, Netsil got off to a great start. Some of their first customers were Fortune 500 companies, and they have since acquired a strong client base on the West Coast.

According to Gill, the success of Netsil is due in large part to its roots in Penn Engineering. “Being at Penn really opened a lot of doors for us,” he says. To further boost the company’s success, Gill has since recruited Penn Engineering alumni who were top-notch students in courses that he taught as a graduate student in CIS. “I’m very proud of this team. They were all undergrads with little experience who later went out to tackle big problems in industry and are stepping up to grow into larger roles.”

The learning curve for Gill and his team was steep, and over the years, they have gained a lot of appreciation for what business people do. “It’s a very tough job,” Gill says. “Research in the lab is not as hard as building something in the real world. But if the product is good, everything else will follow.” 🍷

By Janelle Weaver



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HONORS & AWARDS

Rajeev Alur, *Zisman Family Professor in Computer and Information Science*, has been awarded the Distinguished Alumnus Award (DAA) from the Indian Institute of Technology Kanpur (IITK). This is the highest award given by the Institute to its alumni in recognition of their achievements of exceptional merit.

Danielle Bassett, *Eduardo D. Glandt Faculty Fellow and Associate Professor in Bioengineering*, is the recipient of the 2017 Lagrange-CRT Foundation Prize. The prize, given by the Institute for Scientific Interchange Foundation in Turin, Italy, was created to encourage and honor young researchers working in the field of complex systems.

Robert Carpick, *John Henry Towne Professor and Chair of Mechanical Engineering and Applied Mechanics*, has been named a Fellow of the Materials Research Society (MRS). The fellowship honors those MRS members who are notable for their distinguished research accomplishments and their outstanding contributions to the advancement of materials research worldwide.

Nader Engheta, *H. Nedwill Ramsey Professor in Electrical and Systems Engineering*, has been selected to receive the 2017 William Streifer Scientific Achievement Award from the IEEE Photonics Society. He is being recognized “for development of, and pioneering contributions to extreme-parameter metamaterials in optics and photonics.” He has also been named one of Photonics Media’s “Beacons of Photonics.”

Daeyeon Lee, *Professor in Chemical and Biomolecular Engineering*, is the recipient of the 2017 Soft Matter Lectureship. This is an annual award that honors an early-career researcher for significant contributions to the soft matter field. The recipient is selected by the Soft Matter Editorial Board from a list of candidates nominated by the community.

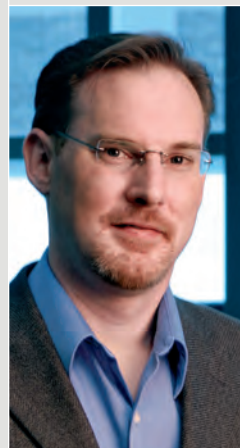
David Meaney, *Solomon R. Pollack Professor and Chair of Bioengineering*, has been elected to the Biomedical Engineering Society (BMES) 2017 Class of Fellows. Fellow status is awarded to Society members who demonstrate exceptional achievements and experience in the field of biomedical engineering.



Rajeev Alur



Danielle Bassett



Robert Carpick



Nader Engheta



Daeyeon Lee



David Meaney



Alejandro Ribeiro



Arjun Raj



Eric Stach



Dan Roth



Shu Yang



Aleksandra Vojvodic

Arjun Raj, *Assistant Professor in Bioengineering*, has been selected to lead one of 38 pilot projects designed to support the Human Cell Atlas. Funded by the Chan Zuckerberg Initiative, Raj's project will entail developing a new method for labeling individual molecules as a way of measuring gene activity in single cells.

Alejandro Ribeiro, *Associate Professor in Electrical and Systems Engineering*, has been named the inaugural director of the Intel Center for Wireless Autonomous Systems. Established with a \$1.5 million gift from Intel, the Center will develop new ways to circumvent the intrinsic physical limitations of cellular and Wi-Fi connections, improving communication within teams of robots.

Dan Roth, *Eduardo D. Glandt Distinguished Professor in Computer and Information Science*, has received the 2017 International Joint Conferences on Artificial Intelligence Organization's John McCarthy Award. He has been recognized for major conceptual and theoretical advances in the modeling of natural language understanding, machine learning and reasoning.

Eric Stach, *Professor in Materials Science and Engineering*, has been elected a 2017 Fellow of the American Physical Society within the Division of Materials Physics. The citation reads, "For development and application of *in-situ* and *operando* methods in materials research using transmission electron microscopy, entrepreneurial activity to commercialize these methods, and for sustained service to the community."

Aleksandra Vojvodic, *Skirkanich Assistant Professor of Innovation in Chemical and Biomolecular Engineering*, has been selected by the European Federation of Catalysis Societies as the recipient of the 2017 EFCATS Young Researcher Award. Vojvodic is being recognized for her computational and theoretical efforts in understanding, predicting, discovering and designing transition-metal compound materials for energy and chemical transformations.

Shu Yang, *Professor in Materials Science and Engineering*, has been selected as a Fellow of the Royal Society of Chemistry (RSC), a professional society based in the United Kingdom with over 50,000 members worldwide. Fellow status applies to society members who have made an outstanding contribution to the advancement of the chemical sciences, or to the advancement of the chemical sciences as a profession.



Alison Newman

Encouraging Technology Leaders

For Alison Newman (C'83), serving on Penn Engineering's Board of Overseers is both a way to give back to her alma mater and a platform to promote innovation. A graduate of Penn's College of Arts & Sciences, she earned a law degree from New York University and is now a corporate partner in the New York office of Fox Rothschild LLP, representing technology clients pursuing mergers and acquisitions, IPOs and venture capital. The desire to share her immense experience on the entrepreneurial side of innovation brought her back to Penn.

Newman devotes time each year to guest lecturing and assessing student business plans in one of the Engineering Entrepreneurship courses taught by Tom Cassel, professor of practice. He notes, "Alison has tremendous insight into what it means to build a life sciences company."

What inspires your involvement with Penn?

My Penn education instilled a sense of social responsibility and gave me transferable skills which prepared me for complex and changing situations. My husband went to Wharton, his three siblings and father went to Penn, my older daughter graduated from Penn and my younger daughter will start there after a gap year, so it's an important part of our lives. I love being able to give something back that goes deeper than philanthropy.

What led you to the Board of Overseers?

Though I studied liberal arts, I was always interested in business. When my legal career turned toward IPOs and venture capital deals, I worked on the development and commercialization of technologies and products from different perspectives, including representing entrepreneurs in working with universities. It made sense to get involved with Penn Engineering, a leader in interdisciplinary education and research.

What is most exciting about this work?

There's so much innovation here. Technology is transforming our lives and the world we live in today. Sitting on the Intellectual Property (IP) committee has been a fascinating way to see the process within a university setting. I've also enjoyed thinking about opportunities to attract more women to the School—a subject that's important to me.

What have you taken away from your participation in the Engineering Entrepreneurship course?

The students put together impressive presentations and come up with thoughtful ways to implement their ideas. It's a demanding course but they're passionate about the work. This course is truly preparing future entrepreneurs for what's ahead and it's rewarding to be part of that process.

By Elisa Ludwig

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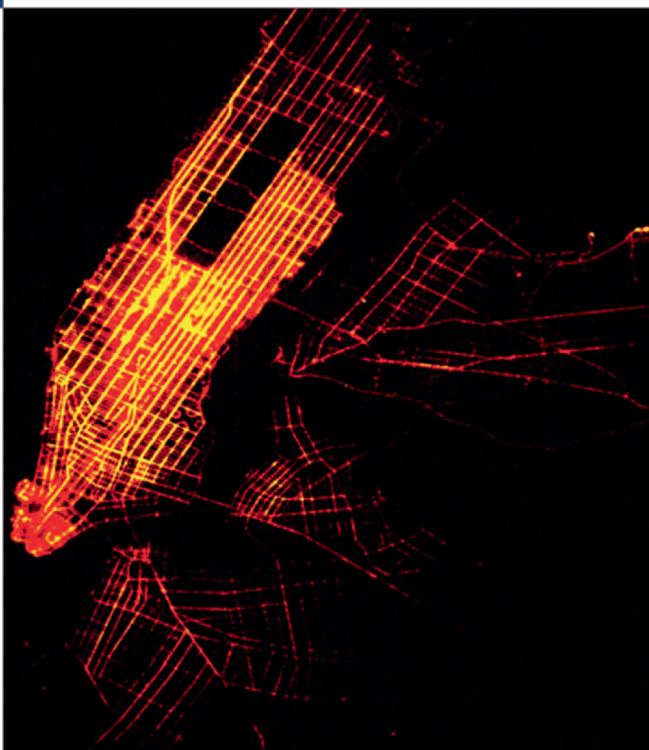


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IoT-Enabled Data Science

Internet of things (IoT) devices sensing our cars, homes and medical equipment are becoming the largest generators of data. How should we use such data in order to improve the safety, security and efficiency of energy, transportation or health? In a recent research project, Penn graduate student Fei Miao, now faculty at the University of Connecticut, used 100 GB worth of data from 700 million taxi rides in New York City collected over a period of four years.

In collaboration with researchers at the University of Virginia and the University of Minnesota, Miao developed data-driven optimization algorithms that use such massive data sets to make more intelligent routing decisions for taxis, resulting in idle-time reductions of more than 30 percent. This could lead to improved transportation efficiency, reductions in environmental emissions, and also significant economic impact for companies like Uber.