



**SHAPING
BIOMEDICINE**

Tracking the
hidden yet
ubiquitous scutoid

See page 10



**BRINGING IT
TOGETHER**

The next chapter
for a hallowed
Lehigh tradition

See page 22

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A FOCUS ON LEHIGH ENGINEERING • VOLUME 1, 2019

CONVERGENCE BY DESIGN

SERVING UP SOLUTIONS AT THE INTERSECTION OF THE HUMAN CONDITION AND THE BUILT ENVIRONMENT

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VOLUME 1, 2019

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It's all about convergence

Welcome to the Spring 2019 issue of *Resolve*—a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh University.

Now in full swing, GO: The Campaign for Lehigh will provide new resources to greatly enhance our strategic growth, particularly around interdisciplinary research excellence and a rich experiential learning environment for our students.

Academia is on the cusp of change in how we shape research and educational programs, and our efforts place Lehigh in the vanguard of institutions leading the way; in many respects, it's all about convergence.

The National Science Foundation (NSF) defines convergence research as “research driven by a specific and compelling problem” that involves “deep integration across disciplines.” At Lehigh, we live convergence, from our integrated undergraduate programs to our Interdisciplinary Research Institutes and everywhere in between.

This issue of *Resolve* highlights key initiatives that embody the concept. To solve complex research problems, we are focusing on societal needs and integrating knowledge, methods, and expertise from a breadth of disciplines to catalyze scientific discovery and technological innovation. Our engineering students experience these challenges head-on through their immersion in the resulting impact-driven ecosystem.

Lehigh's Institute for Cyber Physical Infrastructure and Energy (I-CPIE), one of the university's inaugural Interdisciplinary Research Institutes, is featured on page 12. Launched last year and supported in part by GO: The Campaign for Lehigh, these institutes exemplify Lehigh's approach to, in essence, crashing through intellectual boundaries in pursuit of real, lasting impact.

From smart infrastructure to energy system cybersecurity to Internet of Things connectivity, the topics I-CPIE researchers pursue exist at the intersection of the human condition and the built environment. As never before, I-CPIE brings together experts from

the social sciences and humanities to business and economics to partner with engineers and scientists. Together, they address issues that will guide how people interact with the communities in which they live, work, and play.

Sometimes, as the article on page 10 demonstrates, real, lasting impact comes about in mysterious ways. As a side effect of their study of the formation of organs, Lehigh researchers identified a completely new geometric shape: the scutoid. Beyond the scholarly publication of this important discovery, the internet erupted in glee, producing memes, hashtags, T-shirts, poems, and even late-night TV comedy from Stephen Colbert and Seth Meyers.

But the real significance of this work has yet to be felt, as researchers around the world from a spectrum of disciplines are now realizing that the scutoid has been hiding in plain sight, from something as simple as soap suds to something as complex



Academia is on the cusp of change in how we shape research and educational programs, and Lehigh is in the vanguard of institutions leading the way.

as epithelial cells, since long before Euclid published *The Elements*. Only time will tell what kind of convergence research will be spawned from this discovery.

The refocusing of our interdisciplinary capstone design program, featured on page 22, reflects convergence infused into student learning. The evolution of our renowned Integrated Product Development (IPD) program will support capstone projects initiated through industry partnerships and driven by students' own ingenuity and entrepreneurial passion.

Generations of Lehigh engineers have engaged in the IPD program, and found themselves quickly ushered out of their comfort zones and challenged to dig deep. Now, we are working to include an even more diverse range



of engineering students, along with their peers from design, business, and other majors.

The objective for this new, improved IPD is to add even more dimension to the projects and teams converging around vexing, open-ended problems—the very heart of experiential learning.

Speaking of experiential learning, we are in the formative stages of a transformational plan

to re-create Packard Lab as the heart of experiential learning on the Asa Packer campus, in many ways returning it to its historical roots while re-envisioning the venerable building as an ultramodern engineering headquarters.

These are exciting times for Lehigh and the Rossin College! Thank you as always for your support and engagement. Please drop me a line with your thoughts and comments.

A handwritten signature in black ink, appearing to read 'S. DeWeerth'. The signature is stylized and fluid.

Stephen P. DeWeerth, *Professor and Dean*
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Diplas elected ASCE Fellow

CEE chair lauded for contributions to hydraulic engineering



Panayiotis “Panos” Diplas, the P.C. Rossin Professor and Chair of Civil and Environmental Engineering has been elected as a Fellow of the American Society of Civil Engineers (ASCE).

The honor is given to practitioners and educators who have distinguished themselves as mentors and leaders in the civil engineering profession and whose impact is felt on a global scale. According to the organization’s website, ASCE Fellows are individuals who have made “celebrated contributions and

developed creative solutions that change lives around the world.” The rank of Fellow is a prestigious honor held by less than 3 percent of ASCE’s more than 150,000 members in 177 countries.

“The Society’s Fellow grade is intended to recognize members who have made celebrated contributions to our profession,” says David M. Wieller, PE, President of the Lehigh Valley Section

of ASCE (LV-ASCE) and a senior engineer with Borton-Lawson. “LV-ASCE was delighted to have the opportunity to nominate Professor Diplas for this honor. Through his teaching, research, and professional service, Panos certainly meets the standard.”

LV-ASCE member Stephen Ressler ’89G ’91 PhD, who currently serves as an adjunct faculty member at Lehigh, was also instrumental in shepherding Diplas’ successful nomination through the national process.

“Over the years, the ASCE Lehigh Valley Section has maintained a strong and productive relationship with the Department of Civil and Environmental

Engineering at Lehigh,” says Ressler, who previously served as Professor, Civil Engineering Program Director, Vice Dean for Education, and Chief of Staff of the U.S. Military Academy at West

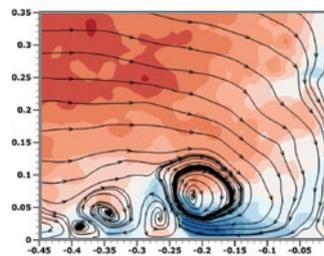
Point. “Panos’ selection as an ASCE Fellow is another wonderful milestone in this great relationship. We extend our hearty congratulations and sincere thanks for

his continuing role in developing future civil engineering professionals for the Lehigh Valley and the nation.”

Diplas and the rest of the 2018 class of ASCE Fellows were honored at the OPAL Awards Gala on March 14, 2019, in Arlington, Virginia.

Diplas takes a big picture approach to solving river-related problems and encourages students to look at water resource problems at the systems level.

“We tend to treat the symptoms rather than the disease,” he says. “If you try to fix a problem by simply putting a bandage on it, you can make it worse or create more problems in the future.”



Measuring impact

Researcher achieves ‘h-index’ milestone



Israel E. Wachs, the G. Whitney Snyder Professor of Chemical and Biomolecular Engineering, has earned an h-index of over 100, based on his Google Scholar citations, placing him among the top 2800 researchers worldwide in all disciplines of all times (from approximately 1900 to the present). The h-index was originally suggested by a physicist, Jorge E. Hirsch, in 2005, as a measure of productivity and citation impact.

Researchers at the top of the h-index list include Sigmund Freud, with an h-index of about 280. This distinguished group

comprises Nobel Laureates, engineers, and scientists in every discipline.

“The h-index is widely used as one of several metrics to gauge impact of the scholarly publications of a researcher,” says Mayuresh Kothare, chair of the Department of Chemical and Biomolecular Engineering. “Reaching an h-index of 100 is an astonishing scholarly accomplishment that reflects the influence that Dr. Wachs’ research has had in the fields of heterogeneous catalysis and chemical engineering.”

Wachs’ research focuses on heterogeneous catalysis (sustainable energy, chemical, and environmental applications)

and surface characterization under reaction conditions (*in situ* and *operando* spectroscopy). He was recently elected as a

Fellow of the National Academy of Inventors (NAI) and is currently on sabbatical at Technion—Israel Institute

of Technology in Haifa, Israel, on a Fulbright Senior Scholar Fellowship.



A turbo boost for materials science

UC Berkeley partnership may reach the edges of the cosmos

Every so often, the search for functional materials—materials designed with properties and characteristics that allow them to do something spectacular—delivers a fundamental change to the way we live. About 5000 years ago, the discovery and use of bronze enabled no less a task than the ushering in of modern civilization. More recently, we've seen silicon's properties give rise to the Information Age, and the advent of products we now take for granted: plastic, stainless steel, composites, titanium, Gorilla Glass, even clothing that will not stain.

Yet discovering new materials is a lengthy process, and Joshua Agar, an assistant professor of materials science and engineering, says it comes about in one of three basic ways.

"Throughout human history," he says, "we've seen materials development occur over thousands of years of trial and error that advances across generations and entire civilizations. Efficiencies began to improve dramatically when society began to conduct physical experiments in increasingly specialized laboratories. This is certainly an improvement, but this approach comes with significant costs as we conduct time-consuming, expensive experiments. Even more recently, though, scientists have begun to use computational simulation to drive research in a wide array of fields, including material discovery. This use of digital technologies is far more efficient than either of the previous methods—yet even here, we can do better."

Increasing the speed of material discovery is but one aim of a sprawling new project being conducted by a research team from Lehigh and University of California at Berkeley, assembled with some \$600,000 in support from the National Science Foundation (NSF) through its recently announced TRIPODS+X program.

"Recent advances in what are called embarrassingly parallel computational methods have enabled machine learning that can draw conclusions from raw data by considering an interlocking multitude of co-dependencies that would

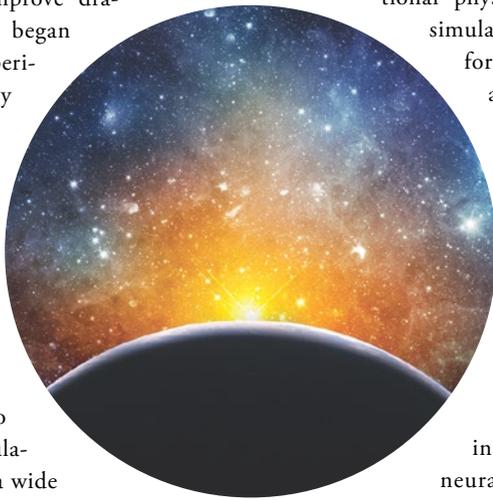
otherwise be beyond human comprehension," Agar continues. "Currently, in order to develop an understanding of these deep, nuanced relationships in the data, we utilize computational techniques that amount to brute-force computation to perform a logical chain of highly efficient functions. It's like using a flamethrower to crisp up a crème brûlée."

Through the project, Agar and his team will create what they term "an efficient Bayesian-guided computational framework" that will guide the development of a neural network—a computer system modeled on the human brain and nervous system—that will serve to turbocharge the search for new and advanced materials with enhanced electrical, thermal, mechanical, and magnetic characteristics.

According to Agar, the project will apply "deep learning neural networks" to more efficiently perform functions associated with traditional physics-based computational

simulation. The team intends for its work to eventually accelerate the work of other researchers in the discovery and synthesis of novel materials; if successful, they also believe the technologies they are developing could have an impact far beyond materials development.

"We believe that the increased efficiency of our neural network model may facilitate the asking of scientific questions that are currently computationally intractable," he says. "The proposed work is specifically focused on enabling a neural network to discover what we call strain-induced polar phases and phase competition in materials. But working with our partners at Berkeley, we believe that some of the foundational data science methods developed through this effort may also help to support astronomy's understanding of the large-scale structure of the universe—cosmology in its grandest sense. It is even possible that these concepts will prove to be applicable to computational simulations across a wide range of scientific disciplines and adjacent fields." 



Tansu named to 'Highly Cited Researchers' list



Nelson Tansu, the Daniel E. '39 and Patricia M. Smith Endowed Chair Professor of Electrical and Computer

Engineering, has been named to the prestigious Clarivate Analytics list of "Highly Cited Researchers" for 2018. The list, published annually, includes researchers ranking in the top 1 percent by citations for field and publication year.

According to the Clarivate Analytics (formerly Thomson Reuters) website, the "Highly Cited Researchers" list "identifies the most frequently cited researchers as determined by the extent to which their papers have supported, influenced, inspired and challenged other researchers around the globe. It identifies authors who have consistently won peer approval from international researchers in the form of high citation counts."

Tansu, who is widely regarded for his groundbreaking contributions to the field of semiconductor optoelectronics materials and devices, appears in the "Cross-Field/Multidisciplinary" category.

Elected a Fellow of the National Academy of Inventors (NAI) in 2016, Tansu has 17 patents and is the author of more than 134 refereed journal articles and more than 279 conference publications. He conducts research on physics, materials, devices, and integrated technologies based on wide bandgap and compound semiconductors for sustainability, health sciences, and computing and communications. 



Safeguarding machine learning systems

NSF CAREER winner on trustworthy software development

We live in the era of software 2.0. An era of computer systems capable of learning desired behaviors, like how to recognize voices and faces, and predicting outcomes, like whether a tumor is benign or malignant. Whereas its predecessor—software 1.0 if you will—is relatively straightforward with its lines of code, machine learning is built on a network of mathematical transformations that parses data, finds patterns, and produces an outcome. These systems are increasingly superior to humans in their accuracy, and they are transforming nearly every aspect of our lives from travel to medicine to entertainment to security.

But such complexity is problematic. Machine learning systems are so large that to expedite their creation, developers often reuse foundational building blocks, or neural network layers, called primitive models. These models are

available online, and it's often unclear who their source is—and whether or not he or she can be trusted.

“These systems are so complicated, it doesn't make sense to build them from scratch,” says Ting Wang, an assistant professor of computer science and engineering. “One way to build a system quickly is to take one model from here, one from there, and put them together. But many models out there are contributed by untrusted third parties. If these models contain a vulnerability, your system inherits that vulnerability.”

Wang recently received support from the National Science Foundation (NSF) to better understand the security implications of reusing these primitive models and to develop tools to help mitigate those threats. His proposal to develop trustworthy machine learning from untrusted models recently won him a Faculty Early Career Development (CAREER) Award.

The CAREER program is considered one of the more prestigious awards granted by the NSF. They are awarded annually in support of junior faculty members across the U.S. who exemplify the role of teacher-scholars through outstanding research, excellent education, and the integration of education and research.

Wang's grant is related to a previous NSF award called Eagle Eye, focused on identifying infinitesimal manipulations to data that triggered deep learning systems to fail.

“Eagle Eye was about how you can manipulate the input, the data,” says Wang. “This new project is about how the system itself can be adversely manipulated. Your data can be great, but your system may already be doomed. So there's an interesting interplay between the two projects.”

Wang calls these system manipulations “model reuse attacks.” And just like in Eagle Eye, their ramifications are potentially disastrous.

“The main concern comes from the increasing use of machine learning systems in all kinds of security sensitive domains like autonomous driving, medical diagnosis, high-frequency trading, and legal document analysis,” he says. “All those applications require high degrees of accuracy, so if you make a mistake, the consequences can be huge. You want to make sure the system is behaving as expected because any vulnerabilities can be exploited.”

Wang, who is affiliated with Lehigh's Institute for Data, Intelligent Systems, and Computation (I-DISC), a hub for interdisciplinary research, hopes that by understanding the threats posed by reusing primitive models, he and his team can develop theories and models to help guide developers as they build machine learning systems. **1**



Ting Wang (right) and Eric Baumer of Lehigh's Department of Computer Science and Engineering are 2019 recipients of the NSF CAREER Award.



NSF CAREER
AWARDS
AT A GLANCE

27%
OF ROSSIN FACULTY
HAVE WON THE
NSF CAREER AWARD

'I want technology to be more humane'

Baumer partners with ProPublica, AEquitas on NSF CAREER project

Algorithms, in many ways, control the beat of modern life.

Algorithmic systems give us the reviews, recommendations, and connections that help us find better products, great movies, and new friends. They can be applied to nearly every facet of our lives—commerce, transportation, advertising—and when they work well, they can enrich and facilitate our experiences at home, work, and play.

But decision-by-algorithm is by no means foolproof: Bias on the part of the algorithm's author can create inadvertent, false associations that serve to mislead decision making or to malign entire cultures.

With support from the National Science Foundation (NSF), Eric Baumer, an assistant professor of computer science and engineering, is seeking to improve

(CAREER) Award from the National Science Foundation.

"I want technology to be more humane," he says. "And for that to happen, a more diverse set of people need to be incorporated into the design of algorithmically-based interactive systems—human beings who are not technologists integrated throughout the design process."

With NSF support, Baumer will develop and test his methods at two nonprofits. AEquitas develops resources for prosecutors related to gender-based violence and human trafficking, and ProPublica is devoted to exposing abuses of power and betrayals of the public trust.

Both groups rely heavily on data but don't necessarily have the tools to help

"It's a lot of text to deal with," says Baumer. "And so it might be valuable to have computational tools that would facilitate this process."

Similarly, ProPublica analyzes reams of political text data for patterns, but lacks the sophisticated systems to do it efficiently.

"Part of what we want to do is look at discursive patterns across different forms of media," he says. "And then you can start asking interesting questions, such as, 'How do those patterns relate to the way the representative actually votes?' or 'How do those patterns relate to campaign contributions?'"

In designing custom systems that will assist the organizations, Baumer will work not only with the users of the data but also with those from whom the data is generated, and those who may be impacted by the data. For AEquitas, that will include prosecutors and plaintiffs. For ProPublica, it will include readers and subjects of the data, such as members of Congress, their staffers, and lobbyists.

"Most participatory design methods are focused on users, the people who are going to use the technology," he says. "When you start talking about these AI and machine learning systems, there are new kinds of relationships that come into play, particularly those people whose data is being analyzed. A major gap in the field right now is that data are looked at purely as data instead of people. You can't engage with the data without engaging with the human beings from whom that data came from, at least not without risking serious harm." 

BAUMER IS DEVELOPING HIS METHODS FOR TWO NONPROFITS, AEQUITAS AND PROPUBLICA.



algorithmic system design methods through a decidedly egalitarian approach. His proposal to develop participatory methods for human-centered design of algorithmic systems recently won him a Faculty Early Career Development

them find what they're looking for. Legal research for AEquitas involves sifting through countless documents to find, for example, patterns of rhetoric or legal codes that can vary across countries, cities, and states.

40
ACTIVE LEHIGH
FACULTY MEMBERS

7
LEHIGH
RECIPIENTS
SINCE MAR 2018

\$150M
IN GRANTS
IN 2018

47%
GIVEN
TO NEW
INVESTIGATORS

307
PROJECTS FROM
120 SCHOOLS

A material without limits

Cheaper production of an unsung industrial substance could make hard stuff easier

Boron nitride has a tough reputation.

In its cubic crystal structure, cubic boron nitride, or c-BN, is one of the most remarkably durable human-made materials ever invented, almost on par with natural and synthetic diamonds. It is widely used across aerospace, defense, energy, transportation, and other industries, in settings where products are intended to withstand truly extreme conditions, or when heavy industry needs to drill, cut, or ground such parts into shape.

The hardy stuff even holds up in highly reactive environments; it demonstrates superior stability against oxidation and unintended chemical reactions with, for example, iron, even at incredibly high temperatures.

Boron nitride also happens to be a semiconductor with electrical properties that could enable electronics manufacturers to build equipment that provides 3 to 4 percent greater power conversion efficiency

than traditional, silicon-based technologies. Think about that: If you multiply that increase in efficiency by the number of electronic devices that require power conversion (hint—all of them), the economic and energy-consumption impact is staggering.

But, according to Siddha Pimputkar, an assistant professor of materials science and engineering, the process of producing cubic boron nitride presents a significant obstacle, and boasts a reputation for being equally as stubborn as the material itself.

“Currently, the synthesis of cubic boron nitride is performed under high-pressure, high-temperature conditions, in the presence of suitable catalysts such as lithium or barium nitride,” he says. “Under these constraints, synthesis is effectively unscalable, and the process of producing any amount of this material turns out to be enormously expensive and energy intensive.”

Working with Kai Landskron, a professor of chemistry with Lehigh’s College of Arts and Sciences, Pimputkar has recently won support from the National Science Foundation (NSF) to find a cheaper, greener way of producing boron nitride. The funding will support their efforts to grow single, centimeter-sized crystals of boron nitride in conditions that are much closer to room temperature and pressure, using conventional, readily scalable autoclave systems.

Pimputkar explains that boron nitride’s true advantage compared with diamond lies in its ability to withstand high temperatures while remaining chemically inert and operational—but current methods of producing it leave much to be desired.

“Synthesis of c-BN crystals is currently possible through the use of what are known as high-pressure anvil systems. It is quite an expensive proposition, and the

size of the crystals produced is limited to somewhere in the range of a millimeter in diameter, which then limits the crystal’s utility,” he says. “Boron nitride has also been produced using a process known as chemical vapor deposition, or CVD. Yet this has not proven to be an economical method of bulk production either, and it yields smaller crystals as well.”

The project seeks to synthesize much larger crystals of cubic boron nitride at a far lower cost and reduced energy consumption than ever before possible; this could open up new avenues of research and development in electronics.

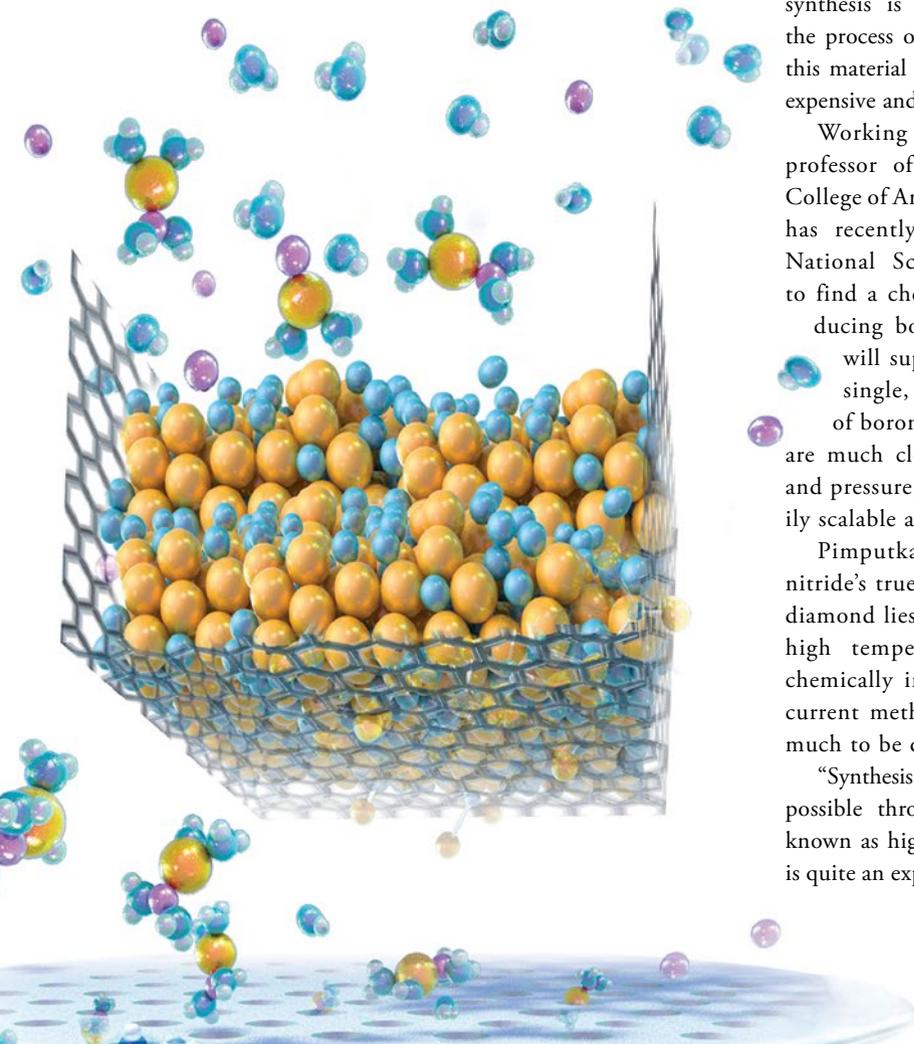
“Development of c-BN single-crystal wafers would create a significant impact in the electronics community as novel, more efficient devices and applications become possible,” says Pimputkar. “This would lead to drastic reduction in power losses for high-voltage power electronics, as compared to the silicon technology in use today.”

Pimputkar also believes that the project could have even broader implications through impact upon the field of high-pressure materials synthesis more generally.

“The practical value of materials synthesized at high pressure is currently quite limited,” he says. “In order to drive wide-scale adoption, the process is simply not viable, and is not easily scalable to the levels that industry would typically need it to be. The techniques we are developing may prove to be applicable in the production of an array of other industrially relevant materials, such as cubic silicon nitride.”

According to the team, if the project is successful, it may also influence the future development of a wide array of technologies, including solid-state UV LEDs, lasers, neutron detection, and instruments for planetary research. **1**

An illustrated schematic of a retrograde solubility ammonothermal system designed to grow single-crystal nitrides.





Harlow elected ASME Fellow



D. Gary Harlow, professor and chair of the Department of Mechanical Engineering and Mechanics, has been named a Fellow of the American Society of Mechanical Engineers (ASME).

The distinction, one of the most prestigious in the field, recognizes outstanding achievements made by longstanding members of the professional society. Of the 130,000 ASME members worldwide, some 3,000 have received the honor.

“Professor Harlow’s remarkable accomplishments in materials reliability research and development make him deserving of this recognition,” says Donald Rockwell, the Paul B. Reinhold Professor of Mechanical Engineering and Mechanics, who shepherded Harlow’s nomination. “Add to that his commitment to educating and mentoring graduate and undergraduate students—including his efforts in supporting varsity student-athletes to meet the demands of Lehigh’s rigorous engineering program—and his contributions overwhelmingly merit the distinction.”

Following the 1988 air disaster of Aloha Airlines Flight 243, in which the airplane lost a section of its roof because of corrosion and metal fatigue, Harlow rapidly became a national authority in the probability modeling of corrosion fatigue of aging aircraft, while collaborating with Robert P. Wei, a Lehigh professor and leading expert in the physics of corrosion.

“Professor Harlow’s foundational contributions to the probabilistic aspects of materials of aging

aircraft have helped ensure the viability of aircraft with an extended period in service through proper monitoring and assessment,” says Rockwell.

Harlow has been centrally involved in programs funded by the Federal Aviation Administration, the U.S. Air Force Office of Scientific Research, and the Defense Advanced Research Projects Agency. His leadership in these programs has led to accelerated design, manufacture, and implementation of landing

gear steel; a statistical model that describes which fatigue cracks in aluminum alloys are critical and eventually lead to failure; and production of structural components using directed energy deposition. More recently, he has contributed his expertise in statistical modeling to the Food and Drug Administration in the qualification of a heart valve.

Harlow pursues research interests in the areas of probability and statistical modeling of failure processes in materials, aluminum alloys, steels, and composites; stochastic fracture mechanics; mechanical and system reliability; applications of stochastic processes; and applied probability modeling. He is also affiliated with Lehigh’s Institute for Cyber Physical Infrastructure and Energy.

Since becoming chair of the mechanical engineering and

mechanics department in 2008, Harlow has recruited a total of 12 new faculty who have won a total of 10 early career awards from major federal agencies and have subsequently secured significant research grants from the Department of Defense, National Science Foundation, Department of Energy, and National Institutes of Health. 

**“ENGINEERING
PROBABILITY AND
STATISTICS
MODELING
HAVE A MAJOR
IMPORTANCE FOR
THE STRENGTH
OF COMPOSITE
MATERIALS.”**

—D. Gary Harlow



Tamás Terlaky elected to INFORMS board of directors

Tamás Terlaky has been elected vice president of meetings of INFORMS, the Institute for Operations Research and the Management Sciences.

In his two-year appointment to the INFORMS board of directors, Terlaky, who is the George N. and Soteria Kledaras '87 Endowed Chair Professor of Industrial and Systems Engineering, will oversee and enrich

INFORMS’s portfolio of conferences and workshops aimed at expanding professional skills and increasing societal impact.



“I am honored to serve the INFORMS community at this exciting time, with the analytics movement, the exploding world of Big Data, and the ever-growing need for data-driven decisions and scientifically well-founded decision-making,” says Terlaky. “Meetings are such an important venue for education and idea generation and they are often where the seeds of collaboration are planted.”

INFORMS is the premier association for professionals in operations research and analytics, with more than 12,500 members across the globe. The institute promotes best practices, publicizes advances, and provides opportunities for networking and professional development. Its annual meeting, held each fall, is the world’s largest operations research and analytics conference.

“Tamás is highly recognized in the operations research community, and INFORMS will no doubt benefit from his leadership and organizational skills,” says Luis Nunes Vicente, the Timothy J. Wilmott '80 Endowed Chair Professor and Department Chair of Industrial and Systems Engineering. “His election adds to a growing list of remarkable accomplishments.” 



GRAPPLING WITH CONVERGENCE

BILL AMELIO ON TECH TRANSFORMATION AND DOING GOOD WHILE DOING WELL

William “Bill” Amelio ’79 ’08H ’18P is CEO of Avnet, Inc., a global technology solutions company with an ecosystem of experts to support customers at every stage of the product life cycle. Previously, Bill held executive leadership positions at Lenovo, IBM, Honeywell, Dell, NCR, and AlliedSignal, as well as his most recent post as CEO of CHC Helicopter. In 2003, Bill and his wife, Jamie, founded Caring for Cambodia, a nonprofit that supports thousands of Cambodian children with educational and health care services. Bill earned a BS in chemical engineering as well as an honorary doctoral degree from Lehigh, and an MS in management from Stanford University.

Q: Tell us about Avnet’s transformation. What are you seeing that’s driving you to lead the firm in this direction?

A: Over the past century Avnet has adapted to several waves of technological change. Now we are reshaping Avnet again because of another: the Internet of Things (IoT)—and all those connected devices out there that bring it to life.

As most companies find out very quickly, it can involve 10 to 12 partners to bring a product to market, making the process very complicated, time-consuming, and costly. Avnet is growing into

a single-source technology solutions company that supplies our traditional devices but also develops the gateway, the network, the cloud, and the analytics for IoT—everything from inception to prototyping, through scale up to production.

Q: How will IoT change the way people interact with their world?

A: It will impact how we make decisions and how we structure our interactions with all sectors of industry. We’re already working with customers on smart urban infrastructures, personalized medicine, efficient agriculture, and predictive maintenance

for equipment. In our own company, we’re using IoT and artificial intelligence (AI) to help us optimize operations, increase customer and employee satisfaction, and unearth new market opportunities.

Q: IoT is also clearly driving a convergence between the built environment—our hardware—and digital environments—our software. How is that impact being felt in industry?

A: The convergence of information technology (IT) and operations technology (OT) poses big challenges for many organizations. One of them is trust: IT professionals need to trust OT devices to connect to carefully constructed networks, and OT professionals need to feel comfortable with a new security stack. End-to-end security from the device to the final application server is so important. For example, we are currently working with Microsoft on Azure Sphere, a groundbreaking new solution for creating highly secured, internet-connected microcontroller (MCU)-powered devices.



William "Bill" Amelio '79 '08H
'18P CEO of Avnet, Inc. and co-founder of Caring for Cambodia, which he started with his wife, Jamie.



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curriculum, and beyond, could play an essential role in closing the skills gap. This is more than just creating a generation of coders—it is about creating new skill sets that we will need in the future. I think industry can help in many ways. Through our Farnell, Newark, and element14 businesses, for example, Avnet is focused on making computing platforms such as micro:bit, Raspberry Pi, and Arduino available to educators and students so they can explore and invent.

Q: For this next generation, what will differentiate leaders from their peers?

A: The ability to think across boundaries—we're going to need more of that. This is an area where Lehigh students excel, because it is a school that encourages its students to see the world in this way. These are individuals who can say, for example, I'm not just a civil engineer, I'm a computer scientist and an entrepreneur too. In the business world, the demand for people who integrate different competencies is only going to increase. You can learn some of it on the job, but you are clearly at an advantage when you're already comfortable in several disciplines.

that. Avnet supports mentoring programs that encourage women to aspire to leadership, and several times a year we celebrate the success of women moving up in management. Across the business world and especially in technology, we're not where we need to be, but we are making progress.

Q: Tell us about Caring for Cambodia, its evolution, and Lehigh's engagement in this effort.

A: My wife, Jamie, and I have had a long-term relationship with Cambodia since we started the program in 2003. We've really developed something special and remarkable over there. We built 21 schools, which graduate about 600 a year, about 6,600 students overall. It has been life-changing to learn how to make education work in a developing country.

In fact, we've just concluded a five-year program with Lehigh's College of Education in research and volunteer work. The team helped develop an understanding of our schools' impact—what's working, what's not, and best practices toward achieving our objectives. That was invaluable in ensuring our team was pointing in the right direction for the future.

Q How did your experience as a Lehigh wrestler impact your life and career?

It's probably the single biggest factor that helps me be so driven. The mental toughness that comes with hating to lose, and getting back up when you get knocked down, is invaluable.

Q: How do you expect this convergence to influence the manufacturing/supply chain landscape in the U.S. and globally?

A: I think supply chains will go through a complete metamorphosis resulting from a combination of emerging technologies. We'll be able to speed up and automate processes by offloading some decisions to machines. AI will help us optimize our operations, increase customer and employee satisfaction, and unearth new market opportunities. However, to fully realize the promise of these technologies, we'll need to shape a new generation of leaders who understand them—as well as the users of these technologies and the people and groups that design them.

Q: As we march forward toward this increasingly tech-centric future, how can schools best equip students to thrive?

A: Many experts are thinking more critically about how computational thinking in K-12

Q: How can we support women in corporate leadership roles?

A: To run a company there are three things you have to do: great strategy process, great execution process, and great talent management process. I spend a lot of time on talent management. And in the talent management process, it's critical that you get more diversity of ideas, gender, race throughout the organization because you get better ideas coming to the table.

Women in leadership is part of that. At Avnet, our own director of business transformation was shocked when she learned that her granddaughter pictured leaders as men—even with her own grandmother in a leadership position at a Fortune 500 firm! So, we have to change

Notably, Caring for Cambodia can boast the highest levels of women in secondary schools, and graduation rate, in the country.

Q: You were a successful Lehigh wrestler. How did that experience impact your life and career?

A: It's probably the single biggest factor that helps me be so driven. The mental toughness that comes with hating to lose, and getting back up when you get knocked down, is invaluable. Coach [Thad] Turner was a great role model, and we're still in contact today. When you wrestle for a top-caliber program like Lehigh, you're competing against the top talent in the country. It makes you believe in yourself. That experience has remained with me. 🙏

SHAPING BIOMEDICINE

The discovery of the scutoid could advance understanding of cell topology and the field of regenerative medicine

This article also appears in the 2019 *Lehigh Research Review*.



During development, tissue made of epithelial cells bends to form complex, three-dimensional structure. The cells curve and pack tightly together to accommodate the bending. Researchers have assumed that epithelial cells retain a uniform shape in three dimensions. Through mathematical modeling and experimental research, biophysicist Javier Buceta and an international group of scientists have discovered that, instead, epithelial cells morph into novel shapes that are not the same from top to bottom.

Buceta, an associate professor of bioengineering and also of chemical and biomolecular engineering, and his colleagues dubbed this new three-dimensional (3-D) shape the scutoid, because of its resemblance to a beetle body part called the scutellum.

The identification of the scutoid was named one of the top math stories of 2018 by the American Mathematical Society. *Discover* magazine's State of Science 2019 issue highlighted the finding as a notable mathematical breakthrough. Scutoids quickly became a pop-culture sensation on Twitter and late-night television as the public humorously fretted for future middle schoolers who would have to calculate the volume of a scutoid, which Buceta described as "a twisted prism with a zipper."

Yet, in the long run, the discovery may be most notable for its contribution to the field of biomedicine.

The team hypothesized that epithelial cells adopt scutoid shapes to pack themselves as efficiently as possible, following a physics principle known as energy minimization. Since then, their hypothesis has been independently validated by the work of an unaffiliated group of researchers that, through a controlled experiment, observed soap bubbles forming scutoid shapes to minimize their surface energies.

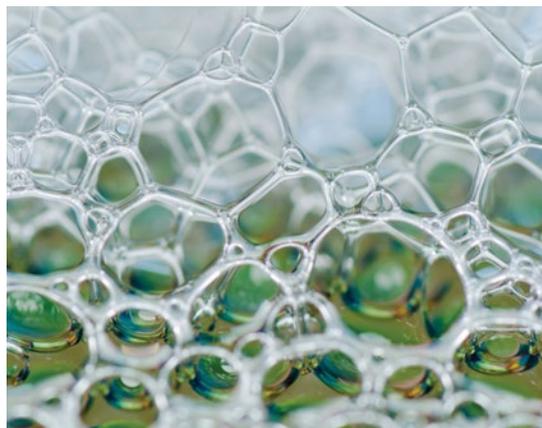
The identification of epithelial cells' 3-D structure has wide-reaching impli-

cations for advancing the scientific community's understanding of cellular topology, as well as the development of artificially grown tissues and organs.

A new paradigm to understand cell health

"It has been known for a while that a lot can be learned about the health of a cell by analyzing its geometry—its shape and size—and topology—its arrangement with neighboring cells," explains Buceta. "Healthy cells follow a certain distribution pattern. A change in this distribution pattern can be observed in unhealthy cells."

"UNDERSTANDING MORE ABOUT HOW THESE SHAPES INFLUENCE CELL AND TISSUE BEHAVIOR WILL LEAD TO NEW STRATEGIES TO PROMOTE NATIVE-LIKE TISSUE FORMATION." —Lesley Chow



An analytical model that assumes a uniform structure is no longer sufficient, says Buceta. The team is interested in delving further into this area to develop new tools that characterize tissues using information about epithelial cells' three-dimensional shape.

"It is now possible to conduct a more realistic analysis that will consider the different cellular relationships and mechanical interactions between the epithelial cells in normal and pathological conditions," adds Buceta's collaborator Luis M. Escudero of the University of Seville in Spain.

"Despite significant progress, tissue engineering and regenera-

tive medicine still falls short when it comes to producing tissues that are duplicates of the native counterpart," says Buceta's Lehigh colleague Lesley Chow, an assistant professor of bioengineering and materials science and engineering.

Buceta and his colleagues believe that the discovery of scutoid-shaped epithelial cells could be used to help advance tissue engineering, which seeks to create living, functional tissues to repair or replace diseased or damaged tissues. It could impact in particular the design of tissue scaffolds, which are biodegradable structures, often implanted, that



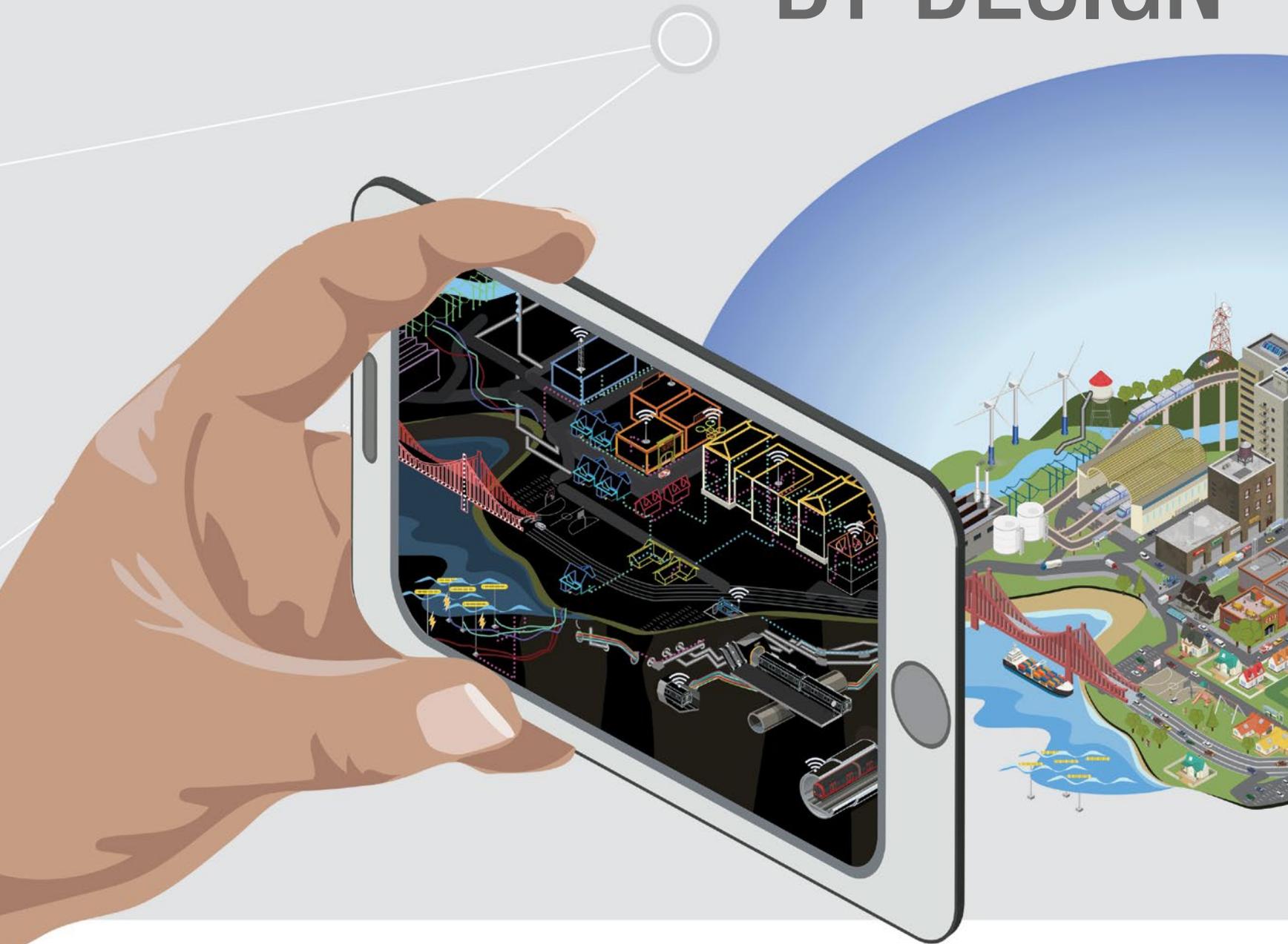
provide the environment for cells to regenerate.

Chow says that this work points to a need for those studying biomaterials to take into account the complex cell-cell interactions and morphologies found in nature, with the hope that "understanding more about how these shapes influence cell and tissue behavior will lead to new strategies to promote native-like tissue formation."

For Buceta, regenerative medicine offers a new area in which to apply the principles of physics to gain a better understanding of biological phenomena—and perhaps help shape the growing and important field of biomedicine. 📍

Javier Buceta (above) says the discovery of the scutoid—observable in skin cells and soap suds—has implications in tissue engineering and other scientific fields.

CONVERGENCE BY DESIGN



THE INSTITUTE FOR CYBER PHYSICAL INFRASTRUCTURE AND ENERGY WAS FORMED TO UNDERSTAND, DEVELOP, AND OPTIMIZE THE CYBER AND PHYSICAL COMPONENTS OF OUR MODERN **INFRASTRUCTURE** AND **ENERGY SYSTEMS**. INTERDISCIPLINARY RESEARCH THROUGH I-CPIE SEEKS TO IMPROVE THE PERFORMANCE, EFFICIENCY, SUSTAINABILITY, AND RESILIENCE OF THE SYSTEMS THAT FUEL OUR ECONOMY AND SUPPORT OUR WAY OF LIFE.

NEW LEHIGH RESEARCH INSTITUTE SEEKS ANSWERS AT THE INTERSECTION OF THE BUILT INFRASTRUCTURE AND THE HUMAN CONDITION



Our day-to-day lives rely on stable infrastructure and a continuous flow of energy. We want to get to where we are going, turn on the lights, drink clean water, connect with friends—without interruption and without giving it a second thought.

With so much riding on the systems that hum in the background of our society, we expect that they are constructed, maintained, upgraded, and rebuilt in a straightforward, rational way, based on science, engineering, economics, and sound public policy.

If only it were so simple.

When a subway tunnel collapses, cell phone service cuts off, or some other system failure occurs, the questioning begins. Why did it fail? Why was it poorly maintained? Why were we unprepared for a catastrophe? Why is it so hard to get back to normal?

“Resilience is a measure of how fast we can restore the functions of these systems after a damaging event,” says Richard Sause, Lehigh’s Joseph T. Stuart Professor of Structural Engineering. “The goal is clear. For example, a storm comes, the power goes off, your phone stops working, and the roads are impassable. Everyone wants it fixed, ASAP. It would be even better if the damage never happened at all.

“Unfortunately, systems like power and transportation often depend on each other. You can’t repair the power without transportation, and vice versa,” he explains. “Perhaps more importantly, we would like to

“WE CHOSE CYBER PHYSICAL INFRASTRUCTURE AND ENERGY AS THE FOCUS BECAUSE OF THE SHEER MAGNITUDE OF THEIR IMPORTANCE TO SOCIETY.” —Richard Sause

think that the processes and decisions to maintain and restore these systems are driven by things that engineers can measure, calculate, or observe. But in reality, these processes and decisions are driven by people, both as individuals and as communities.”

Understanding how humans and society influence the risks surrounding infrastructure and energy systems—and how they cause damage and address the need for restoration—is a challenge that goes beyond engineering. A 360-degree view of the problem requires expertise from fields such as sociology, psychology, and economics.

“Clearly, these are expansive, complex issues,” Sause says. “We need perspectives from many disciplines to find effective solutions.”



Creating an intellectual space for addressing these complex issues—and nurturing large-scale research initiatives as they flourish—is among the top priorities for Lehigh's new Institute for Cyber Physical Infrastructure and Energy (I-CPIE).

"We chose cyber physical infrastructure and energy as the focus because of the sheer magnitude of their importance to society," says Sause, who serves as director of I-CPIE, which shares with its sister research institutes a mandate to attack persistent global problems.

"Infrastructure and energy are two important grand challenges that are closely linked from a systems perspective, and thus it makes sense to address them together. As it turns out, we have some unique capabilities in those areas at Lehigh, so it's a natural fit."

The university has a long-standing and well-deserved reputation in physical infrastructure, structural engineering, and power generation: The Advanced Technology for Large Structural Systems (ATLSS) Center is one of the largest and most renowned structural engineering facilities in the world, and Lehigh's energy researchers have been producing seminal work in fields such as generation, delivery, and environmental mitigation for decades. The university has also made significant investments resulting in robust capabilities in cyber and data sciences.

"WE HAVE TO DEVELOP SOLUTIONS THAT ARE RESOLVABLE OVER TIME, AND WE HAVE TO START NOW."

—Shalinee Kishore

According to Shalinee Kishore, Iacocca Chair and Professor of Electrical and Computer Engineering and I-CPIE's associate director, it is no secret that the nation's infrastructure is in serious need of upgrades. The American Society of Civil Engineers gave the country a D+ grade on its last infrastructure report card, citing a minimum funding gap of more than \$2 trillion. On top of that, with the aftermath

of Hurricane Sandy in the Northeast and other increasingly severe weather events, the race is on to find ways to protect infrastructure that is vulnerable.

"There are more than a dozen critical infrastructure systems in the U.S., which includes the power grid, water, transportation systems, and so on. The point is that it's not a one-shot upgrade at which we can simply throw a couple trillion dollars and make everything OK," she says. "You have to put in new systems and retrofit legacy systems, and all of them have to work together. And even if we install new infrastructure across the board, those systems begin to degrade the next day. We have to develop solutions that are resolvable over time, and we have to start now."

Zero emissions, loads of data

One top-drawer project I-CPIE researchers are currently pursuing would put a significant dent in carbon emissions in California, where the Valley Transit Authority (VTA) in Santa Clara is going electric with its buses. The Lehigh-proposed system would rely on a microgrid infrastructure of interconnected, multipurpose hubs equipped with solar or wind energy converters, power storage units, and command and control systems. Significantly, this could provide a blueprint for future electrification across the state, as California has mandated that all mass transit systems run zero-emission bus fleets by 2040.

Kishore, a collaborator on the project, says that Lehigh's recently established Western Regional Office was a key asset in getting the promising proposal to the final round.

"The Western Regional Office helped us connect with VTA as well as the associated companies needed to deploy a system of this nature," she says. "They were able to go out and talk about our institute and demonstrate connections between the research needs and our faculty expertise. Especially for complex team efforts like this, this kind of exposure and support is crucial."

The planned system for the VTA comprises microgrid stations placed across the sprawling bus routes of the Santa Clara region, which would collect and store electricity for bus charging. The microgrids would be connected to the regional grid for power transfer.

The final component of the VTA plan is data. Lots of data.

"There will be real-time information on the power consumption of the buses, the condition of the roads, traffic congestion, and the state of the power systems across

I-CPIE RESEARCH AREAS



SMART
INFRASTRUCTURE
FOR CONNECTED
COMMUNITIES



INTEGRATED NETWORKS
FOR SUSTAINABLE,
RESILIENT ENERGY
DELIVERY

the network,” says Héctor Muñoz-Avila, Class of 1961 Professor of Computer Science and Engineering, and co-director of I-CPIE’s sister Institute for Data, Intelligent Systems, and Computation, or I-DISC. “The data will be combined and used by the system to distribute the power load, and the system will use algorithms to route and schedule the buses,” he says.

The system will be adaptive and use a specific machine learning tool called reinforcement learning, which in simple terms is an information loop where you feed in data about the environment. Each time the system makes a decision, the results are fed back into the algorithm.

“This is a distinct family of machine learning, and it’s needed because of the sequential decision-making involved,” Muñoz-Avila says. “The decisions that the system makes now will be informed by a decision from the past, and these will inform decisions that the system will make in the future, refining results and learning at each step.”

The electrification of the buses in California will put an increasingly large power draw on the main grid. The microgrids would increase the overall robustness of the grid, and would continue to operate even if other parts of the grid were to go offline because of natural or manmade events.

“None of this will occur in a vacuum, and there are a lot of things that need to be integrated,” points out Shamim Pakzad, an associate professor of civil and environmental engineering. “We have colleagues from urban planning and the social



sciences helping us to understand how and why people make decisions as they use the system. There are specific events that make demands upon the system, such as sporting contests and musical performances that draw large numbers of people, and need to be considered in real time.”

This is a classic example of the need for interdisciplinary collaboration, says Muñoz-Avila.

“I do a lot of research on reinforcement learning, but I really don’t have much experience in energy for transportation systems. It’s not possible for machine learning algorithms to solve the entire problem by themselves. That’s why we have a team of people looking at optimization in the context of a transportation system, putting all the pieces together. That is the only way a project of this magnitude is feasible—people of different expertise working side by side.”

“With this bus system, we have the power generation and distribution system as well as the transportation network interacting directly,” says Pakzad. “That raises some interesting questions, some of which are practical and some are more fundamental as to how infrastructure systems will interface. But all of these projects are part of an effort to use data and other tools to improve the quality of life for people who live in cities and communities.”



Secure systems, connected communities

According to Liang Cheng, an associate professor of computer science and engineering, there is an increased security risk when layers of cybersystems are added together to complement, support, and manage physical infrastructure and its usage. Vulnerabilities can be exploited by nefarious actors or by sheer circumstance; eliminating or protecting those gaps is at the core of his research in cybersecurity, cyber-physical systems, and distributed systems.

“If someone were able to hack the traffic lights of an intelligent transportation network, that is a textbook cybersecurity danger, and would obviously cause a serious problem,” he says. “One can quite easily imagine many similar possibilities.”

Cheng’s work focuses on real-time sensing, model-driven data analytics, and the Internet of Things. As an example, programmable logic controllers (PLCs) are critical components of automated industrial control mechanisms, processing data in real time to keep systems running smoothly. They are also attractive targets, and Cheng cites the Stuxnet attack on Iran’s uranium enrichment centrifuges as a famous example.



LARGE STRUCTURAL SYSTEMS OF THE INFRASTRUCTURE



RESILIENT INFRASTRUCTURE AND COMMUNITIES



CYBERSECURITY FOR ENERGY AND INFRASTRUCTURE

“The engineering workstation in that system was compromised, and the attackers were able to gain device programming privilege to alter the control programs running on the PLCs,” he says. “By first identifying PLCs that can be hacked and then modifying their control programs, they changed the speeds of the centrifuges and produced vibrations which destroyed them.”

Cheng and Mooi Choo Chuah, a professor of computer science and engineering, along with PhD student Huan Yang, have successfully designed and tested an automated protection system that uses time-based signal analyses to detect suspicious variances in a PLC’s command executions.

“We insert checkpoints in the payload and modify the firmware to time-stamp critical I/O and network operations,” Cheng explains. “This allows us to find out how many milliseconds there are between different operations. If there’s an abnormal delay, a human operator is quickly alerted to inspect the issue.”

Some of Cheng’s other research has implications for the Internet of Things and blockchain-based applications, and provides rich possibilities for interdisciplinary work with social scientists, economists, health care professionals, and citizen scientists.

“TOGETHER, WE DEvised A DISTRIBUTED AND NETWORKED ALGORITHMIC SYSTEM...THIS METHOD IS A MORE EFFICIENT WAY OF ASSESSING THE OVERALL CONDITION OF THE BRIDGE.”

—Liang Cheng



“Think about if you could monitor smart meters or share appliance information in the home,” he says. “Social service agencies fed that data could be informed if an elderly resident had not used a stove or turned on a television for an irregular period of time, and have someone look in.

“Crowd-sensing and crowdsourcing enabled by blockchain technologies are places where you could do a lot of good,” he continues. “For example, my team is studying the use of data from cars on less traveled secondary and tertiary roads to notify authorities and other drivers of road conditions. It’s an interesting problem: There is a huge amount of data with a lot of noise that needs to be filtered to make the information useful.”

Cheng has also collaborated with Pakzad in creating an automated monitoring system for bridges.

“The work that I’ve done with Shamim is highly interdis-



ciplinary, designing new computational and networking algorithms to process the data collected by wireless sensors on the bridge,” says Cheng. “Together, we devised a distributed and networked algorithmic system. Every monitoring node on the bridge does a computation to identify the local conditions, then forwards that information to the neighboring nodes. Previously, civil engineers had relied on a centralized process. This method is a more efficient way of assessing the overall condition of the bridge.”

Abundant energy, expertly extracted

Teams of I-CPIE researchers are also looking into ways to extract energy from the motion of water in the seas. According to estimates by the World Ocean Network, 50 percent of the globe’s population resides in coastal areas, and that figure could be as high as 75 percent by 2025.

Ocean wave energy generation has massive upside potential, and while there are high hurdles to surpass before that can be fulfilled, it is tantalizing to consider the possibilities. Marine hydrokinetic energy generation in the United States from combined ocean and tidal sources has the capacity to top 1,400 terawatt hours annually, most of that ocean wave energy. That could provide up to 40 percent of the nation’s energy needs, says Arindam Banerjee, an associate professor of mechanical engineering and mechanics.

“But these are very unforgiving and harsh environments,” cautions Banerjee, who has been working on the energy-water nexus with Kishore and other members of I-CPIE.

The current designs for ocean wave power generation use float and absorber—the float bobbing up and down with the waves in a piston-like movement, and the absorber remaining static, engaging a linear generator inside.

“What we are going through now is a design space shakeout,” says Banerjee. “Like with wind turbines, if you go back 40 years, you used to see a lot of different designs, and the industry has settled on a three-blade rotor design. That is what we’re doing with wave energy now, working towards the ideal design shape.”



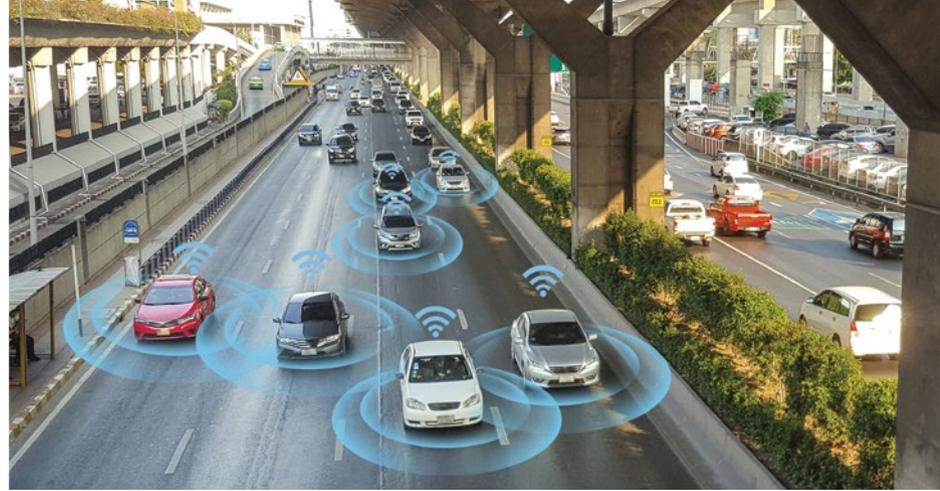
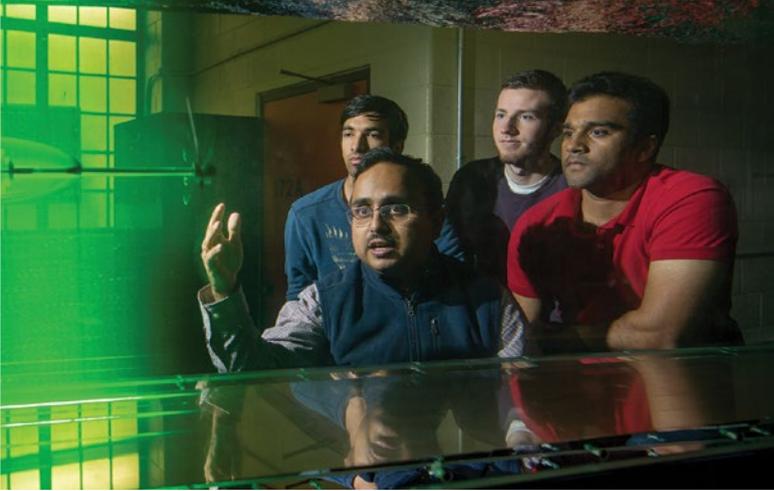
ENERGY-WATER NEXUS



TECHNOLOGIES FOR CYBER-PHYSICAL SYSTEMS AND INTERNET OF THINGS



ENERGY, POWER, AND RESOURCES TECHNOLOGIES



Besides the design, there are complex physics and modeling problems to be solved to extract the maximum possible energy from a farm of generator buoys placed in the ocean. Banerjee estimates now that 30 buoys could eventually produce enough energy to power 300 households, but there is some highly intricate modeling required to reach that ideal.

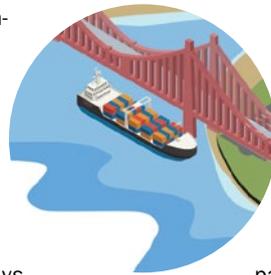
“Energy convertors need to be very precisely controlled,” says Rick Blum, the Robert W. Wieseman Research Professor in Electrical Engineering. “One way that this can be achieved is to accurately predict future wave activity.”

Blum and collaborators have developed techniques and low-complexity algorithms for these predictions, based on measurements taken from sensors around the convertors. The team also characterized the negative impact of inaccurate predictions, along with other losses present in real systems. (Blum’s work also has implications in cybersecurity; see page 18.)

Larry Snyder, a professor of industrial and systems engineering, working with Blum and Banerjee, has been researching how to best situate the buoys and how to understand the dynamics of ocean water movement for maximum benefit.

“Think about a wave that hits a device and then transforms because of the device. The next device the wave hits will see the transformed wave and be able to absorb a different amount of energy because of the transformation,” Snyder explains. “That amount of energy can be either higher or lower than it would have been without the first device. The arrangement of devices therefore has a big impact on the total energy produced by a wave energy farm. We have been developing optimization models for addressing this problem.”

One advantage that ocean wave and tidal energy technologies have over renewables like wind or solar is that the energy production is more predictable. A surprise cloudy day or down-tick in wind speeds can decrease the amount of electricity a solar array or wind turbine will produce. “If you’re an independent power producer and you’re going to be penalized for deviation, what is your optimal strategy?” asks Alberto Lamadrid, an associate professor of economics with joint appointments in Lehigh’s College of Business and the Rossin College, who is a partner on the project.



Lamadrid calculates that ocean wave energy generation is on average 15 percent more predictable than wind and solar energy, a significant advantage.

“One of the main factors you have to consider here is ancillary services, which is the way energy producers cover shortages when they can’t meet promised production levels,” he explains. “It’s akin to short-term insurance. If I can’t meet the energy coverage I promised, I need someone to help me cover the gap.”

Lamadrid believes ancillary services are currently undervalued domestically, and thus the reliability of hydrokinetic power generation offers an interesting opportunity in the energy market.

Besides reliability, there are myriad other economic factors a renewable energy producer must evaluate when linking to the grid, and deducing the best course of action is a tangled affair. Lamadrid’s work involves a dizzying balance of time parameters, market prices, storage capacities, and much more to extract the best course in any given moment for hydrokinetic generators to interface with the market.

Verdant Power, a New York-based company, will soon be putting the first underwater tidal turbine farm into the East River to capture the energy of tidal flows.

“This will be the first time that there’s going to be tidal power generation from a tidal farm that is connected to the

“EVEN IF WE DON’T REAP THE BENEFITS DIRECTLY, THE NEXT GENERATION WILL. THAT MOTIVATES ME AS A RESEARCHER AND AS A PERSON.”

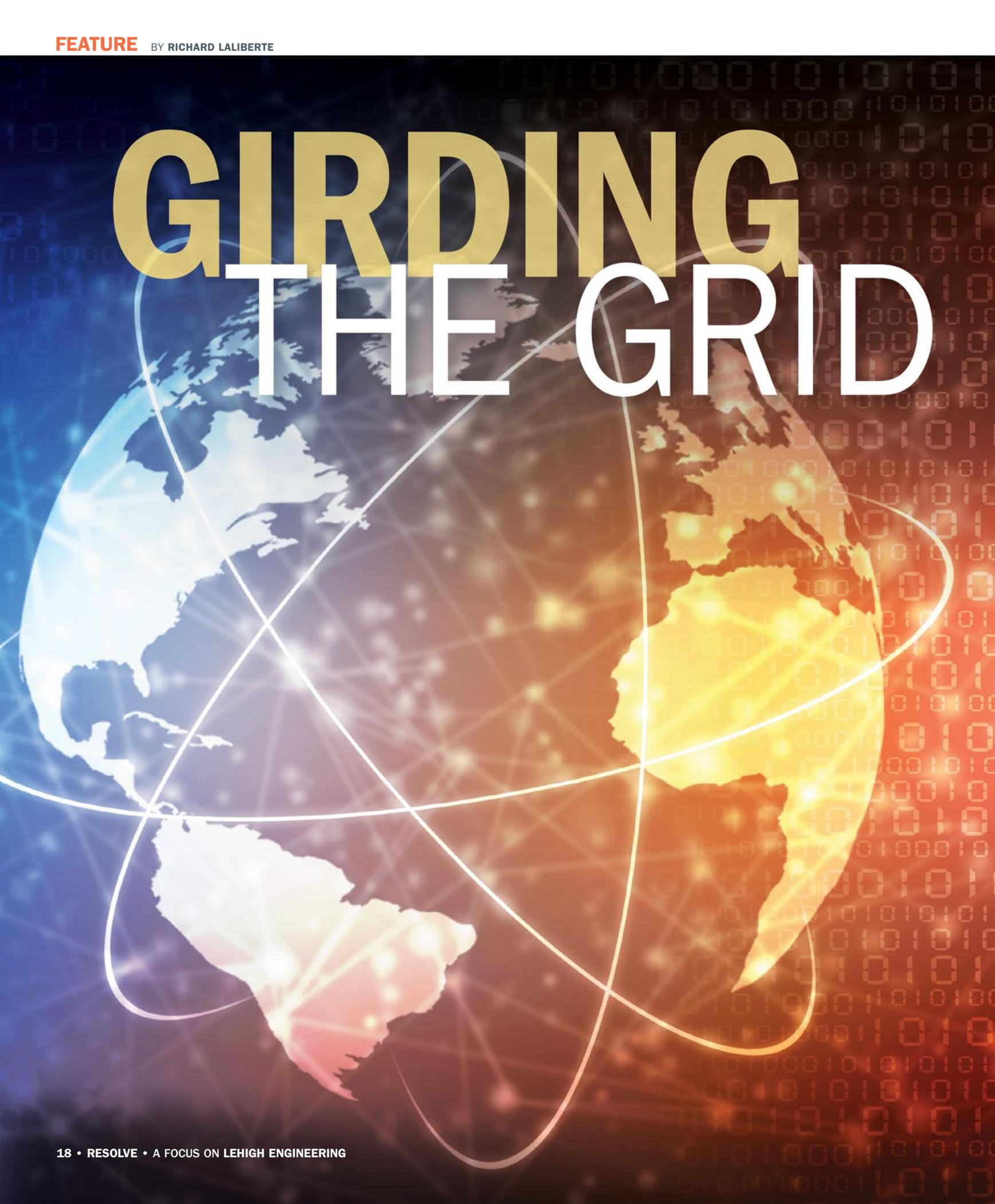
—Arindam Banerjee

power grid in the continental United States,” says Banerjee. “We’ve done a lot of testing, and of course the open environment is quite different from simulations or what you see in the lab, but we are very excited.”

The Roosevelt Island Tidal Energy project has a 10-year license and is slated to generate one megawatt of electricity from the back and forth flows of the East River, a tidal estuary in New York City.

“I have been working on this technology for more than a decade, and I’d really like to see it evolve,” says Banerjee. “Even if we don’t reap the benefits directly, the next generation will. That motivates me as a researcher and as a person.”

GIRDING THE GRID

The image features a central globe with a grid overlay, set against a background of binary code and glowing lines. The globe is split vertically, with the left side in blue and the right side in orange. The grid consists of white lines that intersect to form a network. The background is dark with a pattern of glowing binary code (0s and 1s) in orange and white. The overall aesthetic is futuristic and technological.

RESEARCHERS DEVELOP NEW APPROACHES TO CYBERSECURITY IN THE AGE OF IoT



The more connected things are, the more vulnerable they become. This truism of cybersecurity has profound implications for the Internet of Things that's just around the corner—and for the energy grid that will power it.

That smart thermostat, video doorbell, or Amazon Echo you've set up in your home provides just a foretaste of what's ahead for both consumers and industry.

"As more products and pilot programs become available, a lot of people already have the bare bones of an Internet of Things," says Shalinee Kishore, a professor and Iacocca Chair of Electrical and Computer Engineering who serves as co-director of Lehigh's Institute for Cyber Physical Infrastructure and Energy (I-CPIE). "With the advent of 5G cellular, we'll see far more people and industries participating in a matter of a few years."

With IoT, as it's known, all manner of devices, appliances, and equipment will communicate and interact not only with each other but also with the power grid. The grid in turn will become smarter—meaning both attuned to information and demands throughout its networks and able to respond nimbly, efficiently, and reliably to changes in the flow of energy, data, and money.

Cyber systems have become critical for monitoring the grid, both to understand what's happening system wide and to respond to troubles—traditionally physical—like downed power lines or failed equipment.

"Now cyber systems that shore up the grid are also points of vulnerability," Kishore says. "Instead of attacking equipment, malicious agents could attack the cyber systems that monitor and control electricity. The grid ran for decades without cybersecurity concern, but there's a new layer of complication that you get by making the grid smarter."

Concern about cybersecurity for energy systems led the Department of Energy (DOE) to fund a five-year grant shared by Lehigh and four other universities in conjunction with industry partners to research various aspects of cybersecurity for energy delivery. The work is coordinated through a joint Cybersecurity Center for Secure Evolvable Energy Delivery Systems (SEEDS) spearheaded by the University of Arkansas.

Lehigh is now past the midway point of its \$3.5 million grant but is focused on interconnected cybersecurity research that goes far beyond the scope of the DOE project. (SEEDS may continue with industry support after federal funding expires.)

"All cyber physical systems need to be protected," says Rick Blum, the Robert W. Wieseman Professor in Electrical Engineering, who leads the Lehigh team in this effort. "Cybersecurity is important not just for the grid but for numerous other energy, commercial, and defense systems, many of which could pose dangers if we don't get this right."

CYBER LIES

A cyberattack on the grid would likely seek to cause power failures. Disrupting electricity flow can damage equipment, possibly leading to further outages or even cascading blackouts. Beyond causing social and business turmoil, such failures have the potential to endanger lives.

By cutting power to health care facilities or sick people who rely on medical equipment at home, or by directly harming utility workers handling equipment that's damaged, overloaded, or mistakenly thought to be turned off, bad actors could wreak real havoc on a community.

But attacks could play out in a variety of ways. Data falsification is one threat. Attackers may implant data that makes the grid look like it's running fine when it's not—or has problems when it doesn't.



"Either way, falsified data can mislead operators and prompt them to take incorrect measures that could disrupt electrical flow and damage equipment," Kishore says.

Cyber lies could also wreak havoc with economic transactions tied to swings in supply and demand. One scenario involves what's known as locational marginal prices. LMPs allow the cost of wholesale electricity to reflect the value of energy at different locations in the grid based on patterns of generation, load, and physical limits on the transmission system. The interplay is a bit like using a taxi or Uber: Travel costs—whether for riders or megawatts of electricity—are relatively low when it's easy to get from one point to another but become pricier when demand surges and/or the route congests.



Price fluctuations can prompt electricity consumers to seek a financial payoff by withholding demand when energy costs appear high—like a rider who opts to travel outside of rush hour. This concept, called demand response, will increasingly become available to consumers as a feature of the smart grid. An attacker who falsifies energy pricing could throw off financial balances—or trigger surges of energy into lines and equipment that are dangerously unprepared for them. Incorrect exchanges could lead to losses or disturbances with a variety of serious consequences.

BEYOND THE GRID

Experts like Blum—who was named a 2018 IEEE Signal Processing Society Distinguished Lecturer and speaks often on cybersecurity topics—believe the greatest cyberattack dangers may lie outside the grid.

Energy industries are highly regulated and very careful about what they do. In fact, cybersecurity research in the energy sector can be challenging because grid operators are often reluctant to share real-world data about how their systems actually behave.

“NOW CYBER SYSTEMS THAT SHORE UP THE GRID ARE ALSO POINTS OF VULNERABILITY.”

—Shalinee Kishore



“I’m much more worried about commercial applications of Internet of Things systems,” he says. “These are much less protected. Who will provide security, and how? Will manufacturers do it? This is much less clear.”

He cites the example of rapidly developing driverless cars, which include technologies familiar to Lehigh

researchers and students such as systems for communications, radar, sensor processing, and statistical decision-making. It’s known that radar systems of interest to car manufacturers can be cyberattacked. So can GPS.

“It’s not hard to spoof a GPS system,” Blum says. “The signals are completely known, and nearly any electrical engineering undergraduate could build a fake GPS transmitter very easily and inexpensively.”

Biomedical devices are another example. In an IoT world, sensors in the body might monitor health and find problems early. Sensors might even convey information to tiny smart devices in the body capable of fixing problems before they become severe.

“Imagine if these kinds of systems are cyberattacked,” Blum says. Driverless cars might be hijacked for terrorist strikes—perhaps remotely. Drones could be at risk in similar ways. Attacks on medical devices could taint health data or interfere with function.

Vulnerabilities in commercial Internet of Things systems could also work back to the grid. Imagine that your home becomes a cyber physical system in which smart devices make decisions—based on your preferences or behavior—about lighting, temperature, and appliance use guided in part by demand response to energy use throughout the grid.

“All these systems are interdependent,” Kishore says. “In effect, each device can become a portal to the larger network. You buy a device from Amazon and you don’t know about its design and manufacturing. It might have serious security holes. If an attacker finds one hole in one device, every person using that device can potentially cause problems with the smart grid.”

LAYERED PROTECTION

Cybersecurity defenders work at a disadvantage. “We have to assume attackers have infinite time and resources, and could strike at any moment,” Kishore says. “Defenders, on the other hand, have limited time and resources, and no warning.” Given the multitude of malicious possibilities, no single security approach can be relied upon.

“We’re looking at providing many layers of protection,” Blum says. “Some are well-known ways to keep people out of the system like firewalls and encryption. At Lehigh we’re looking at new approaches. Among them are methods of thwarting attacks even if bad actors breach a system.”

One approach is to build on the wealth of data provided by constant measurement.

“This is the way the grid is going,” Blum says. “We have a lot of sensors monitoring voltage, current, power flow, and a wide variety of other variables at any given

time. Historical data—including past energy usage patterns, weather conditions, and system configurations under specific circumstances—can be used to produce mathematical models of how the grid should look in different situations. When combined with current sensor measurements, anomalies stand out.

“If somebody gets into the system and tries to issue commands for certain things to happen, we can realize these commands don’t make sense,” he continues. “Given enough data and measurements to pool with machine learning algorithms, we can judge what is reasonable and what is inconsistent or an outlier.”

This may become important for shoring up vulnerabilities introduced with greater reliance on renewable energy sources such as the sun or wind.

“With renewables, the supply-side grid looks very different than when a coal plant just generates whatever kilowatts are needed,” Kishore says. Wind and solar generation are inherently volatile, surging and waning with the weather—an opportunity for attackers exploiting uncertainty to make false data look real.

“We’re developing algorithms to find data injection attacks that mimic renewable generation,” Kishore says. “Imagine that a wind farm connected to a power line typically generates 10 to 10.5 megawatts. An output of 9.6 megawatts may seem reasonable, given the variability. But by using machine learning algorithms, we can hone that judgment through probabilistic forecasting. The probability distribution shows that a 9.6 megawatt reading actually is not probable; the algorithm tells you that something doesn’t seem right.”



**“I’M MUCH MORE WORRIED ABOUT
COMMERCIAL APPLICATIONS OF INTERNET
OF THINGS SYSTEMS.”** —Rick Blum

TIME BANDITS

Identifying inconsistencies—or understanding anything about how a system is working now or has worked in the past—requires the entire system to agree on what time it is. GPS can be used for timekeeping, as can a widely used standardized protocol known as IEEE 1588. This protocol efficiently sets clocks throughout a system by having them synchronize via communication channels with a relatively small number of master clocks.

“We understand how someone could get into the system and conduct time-synchronization attacks,” Blum says. “Such attacks wouldn’t need to falsify data—just delaying sensor measurements could prove highly disruptive in IEEE 1588. We now have algorithms that allow systems to keep time accurately even if they’ve been attacked.”

“Timekeeping protection has value beyond power systems,” he continues. “What we’re doing is significant for a variety of applications, including cellular base stations. Cellular devices are now able to talk to several base stations at the same time, so clocks in those systems need to be highly accurate.”

Cybersecurity will continue to be important for broader arrays of technology as they increasingly become connected. Interdependencies are growing even between energy industries.

“A third of electrical generation now comes from natural gas,” Kishore says. “Plants that convert natural gas to electricity are connected to two grids—gas and electricity—at the same time, and this interdependency introduces vulnerabilities all its own. Even if the electrical grid is protected, it has security holes through the natural gas network, which is more localized and fragmented. We’re looking at cybersecurity between the two from many angles, starting with communications systems—what’s needed, how to make them secure, and what they would look like under different policy scenarios.”

Such blended issues play to Lehigh’s strengths.

“We’re able to look at policy, market, and technology solutions with both a wide view and deep expertise through various disciplinary and methodological approaches,” Kishore says. “It’s the whole gamut required to address cybersecurity for large-scale systems.”



DON'T CALL IT A COMEBACK

INTERDISCIPLINARY CAPSTONE DESIGN REENERGIIZES A HALLOWED LEHIGH TRADITION

It was the ugliest prototype you could imagine, a cross between a poorly maintained aquarium and a plumbing experiment gone horribly wrong.

Bacteria had started growing on it. It smelled bad. It was made of acrylic, but her team hadn't known how to glue acrylic so it was kind of a mess. But it worked.

The bench scale, three-stage bioreactor Sabrina Jedlicka and her team had built for their capstone project during their senior year could actually remediate the sugary waste produced during

“COMMUNICATING ACROSS DISCIPLINES IS CRITICAL TO ADDRESSING THE WORLD'S CHALLENGES, SO WE NEED TO TRAIN OUR STUDENTS TO THINK BEYOND THESE DISCIPLINARY SILOS.”

—Sabrina Jedlicka

food manufacturing. The kind of waste that, when released into aquatic ecosystems, causes microorganism blooms that degrade water quality and harm wildlife.

“Our team was given this really open-ended design challenge from a professional society,” says Jedlicka, an associate professor of materials science and bioengineering. “They just said, ‘Remediate sugary waste.’ After evaluating many options, we decided to build a bioreactor. At the end of the year, everyone, especially our team, was surprised that this crazy contraption worked. It was not an elegant design; it was downright ugly, but we were so proud.”

Jedlicka will never forget that experience—the teamwork, the aha moments, the sense of ownership. As she takes the lead of an ambitious effort to grow Lehigh's renowned Integrated Product Development program (IPD) into a campuswide interdisciplinary capstone design program, one of her goals is to ensure her students leave the course with a similarly unforgettable memory.

“Capstone design should be a joyous experience,” she says. “I vividly remember realizing, *I learned this concept as a sophomore, and this skill last semester, and it turns out these things actually are related! They do apply to solving engineering problems!* The capstone represents that moment in your academic career when you get to integrate the concepts from your coursework; during the capstone experience, students should see how the physical, the analytical, the technical, and the other skills they have gained fit together.”

According to Jedlicka, growing the IPD program to include projects that appeal to a broader base of students—and finding new ways to incorporate students from other majors across campus—is a natural evolution of Lehigh's heritage in easing the boundaries between the classroom and real-world problems.

“Communicating across disciplines is critical to addressing the world's challenges, so we need to train our students to think beyond these disciplinary silos,” says Jedlicka. “The best way to prepare them is to give them projects with no easy solutions; projects that require a team approach. We want them to work together, applying their unique skill sets and perspectives to problems they would encounter in the workforce.”

When a team of Rossin faculty came together to increase overall student engagement in experiential learning, the plan to broaden the IPD program, collaborating with other successful programs across campus, quickly rose to the top of their to-do list.





Lehigh students engage in projects that cover topics from fabrication to food systems to prosthetic limb development.

“Several successful project and capstone programs exist at Lehigh, both within and across departments,” says Jedlicka, who was on the faculty envisioning team. “And, with the rise of other innovative teaching modes around campus, such as Lehigh’s Mountaintop Initiative and the impact of the university’s KEEN partnership in rethinking our approach to curricular design, collaborating across these programs to ensure that students find joy in their capstone design is a natural next step.”

Jedlicka notes that, if nascent plans to reconfigure swaths of Packard Lab are successful, the program will eventually have a home in a creatively appointed “maker space” that will facilitate teaming and project management.

“We are thinking big,” she says, “just like we ask of our students. If we can make this happen, this will in some ways be a return to Packard Lab’s origin story as a hub of student innovation and hands-on, project-based learning.”

This year, 188 students on 34 teams are working closely with a faculty advisor, senior peer mentor (a student who recently completed the program), and sponsor mentor. Along the way, they present their projects in a variety of venues and contexts, such as the Lehigh Design Expo, now in its second year.

“There’s stuff flying around the room, it’s noisy,” says Jedlicka. “You can feel how excited the students are about what they’ve done. Some of them have never built anything before, so this is huge for them, to be able to hold something in their hand and say, ‘We did this. This is ours.’”

Sponsors get plenty of benefits, too. While the program is educational, the student teams strive to bring value to the sponsor in areas including product feasibility, customer and stakeholder needs, manufacturing strategies, potential risks, intellectual property analysis, and product concept genera-

tion. Plus, sponsors make connections with the students who are working on their project; a value to both the company recruiting future employees and the students who will eventually be seeking employment.

When her capstone project was completed last year, bioengineer Anne Behre '19 wasn't quite ready to walk away. So she's back this semester as a senior peer mentor, helping guide students who have since taken over her team's work on an ongoing project to develop and refine an HIV-monitoring device.

“It was the most rewarding project I've done at Lehigh,” says Behre. “People were working together and teaching each other. I learned a lot of lab skills that I wouldn't have otherwise. It was hard and it was time-consuming, but at the end I was so proud of myself and my team. As a direct result of all that time and effort, we ended up with something real.”



AN AWARD-WINNING INNOVATOR IN CURRICULUM AND PROGRAM DEVELOPMENT, John Ochs joined Lehigh University’s mechanical engineering and mechanics department in 1979 and founded and directed its Computer-Aided Design Labs. Beginning in 1996, he directed Lehigh’s innovative Integrated Product Development program, which evolved into the highly lauded Technical Entrepreneurship Capstone program; he also served as founder and director of its TE Master’s program. Ochs helped to shape the mission of the Kern Entrepreneurial Engineering Network (KEEN) when it was launched just over a decade ago, and has served as Lehigh’s point person in leveraging its tool kit toward innovating student learning environments. Through his mentorship and guidance in engineering with an eye toward real-world impact, Professor Ochs, who retired in early 2019, has positively influenced the future of countless Lehigh students, especially in the Rossin College.



Xiaochen Guo conducts research that leverages emerging technologies to build energy-efficient processors, memory systems, and accelerators.

Cultivating tomorrow's technology

NSF CAREER winner on defying the limits of Moore's Law

As you waste your lunch hour scrolling through cat videos, snarky celebrity-bashing memes, and videos from your niece's third birthday party, for just a moment consider the majesty of the system behind the screen that enables such lightning-fast access to literally everything under the sun.

When users request files, images, or other data from the internet, a computer's memory system retrieves and stores it locally. In terms of a computer's ability to quickly process data, a relatively small hardware storage called cache is located close to the central processing unit, or CPU. The CPU can access data from the cache more quickly than fetching it from the main memory, or over the open airwaves of the internet.

Data is often gathered into cache in chunks. Based on a principle called locality, when a user accesses one bit of data, the system fetches the adjacent block of data. This happens, in theory, to improve efficiency—in case additional local data is requested in the future, or you decide you need to watch that cat falling into the fish tank one more time. Cache makes it happen instantaneously.

But as applications become ever more complex and user behavior becomes increasingly random, says Xiaochen Guo, P.C. Rossin Assistant Professor of Electrical and Computer Engineering, fetching a large chunk of data becomes a waste of energy and bandwidth.

As she explores ways to solve this conundrum, Guo is supported by a prestigious Faculty Early Career Development (CAREER) Award from the National Science Foundation (NSF), granted annually to rising academic researchers and leaders who serve as role models in research and education.

"Our goal is to improve data movement efficiency by revamping memory systems to proactively create and redefine locality in hardware," she says. "New memory system designs through the project hold the potential to unlock fundamental improvement, and we believe this may in turn prompt a complete rethinking of programming language, compiler, and run-time system designs."

Most previous attempts at solving this issue, Guo says, focused on increasing memory overhead. Eventually, such a system will use more and more storage for metadata, which simply identifies stored memory.

"Reducing metadata is a key focus of our work," says Guo, who is also a two-time winner of IBM's prestigious PhD Fellowship. "Memory overhead translates directly to cost for users, which is why it's a major concern for hardware companies who might be considering new memory sub-system designs."

Reading a picture pixel by pixel is generally a simple enough task for a computer, and locality turns out to be fairly good. But when a system runs multiple tasks at once or performs something fairly complex—think about the random scrolling and clicking that defines your social media habits—Guo's designs can enable hardware to learn and eventually predict patterns based on past and present behavior. When these predictions are perfected, the system will fetch and cache only the most useful data, and thus far preliminary results have been encouraging.

"For our preliminary work on fine-grained memory, the proposed design achieves 16 percent better performance with a 22 percent decrease in the amount of energy expended compared to conventional memory," she says. "This is an especially important topic when it comes to machine learning. The entire community is looking at how to accelerate deep learning applications. Improving the way that memory systems recognize complex patterns will improve the performance and scalability of deep learning applications, enabling larger models with higher accuracy to be run, quite quickly, on smaller devices.

This allows for a highly desirable combination of increased

application performance and decreased energy consumption."

GROWING COMPUTERS IN PETRI DISHES

Will the computers of tomorrow be manufactured, or will they be cultivated?

This question lies at the heart of a team-based project Guo is undertaking that aims to engineer a neural network from actual living cells, and program it to compute a basic learning task.

"Recent developments in optogenetics, patterned optical stimulation, and high-speed optical detection enable simultaneous stimulation and recording of thousands of living neurons," she says. "And scientists already know that connected biological living neurons naturally exhibit the ability to perform computations and to learn. With support from NSF, we are building an experimental test bed that will enable optical stimulation and detection of the activity in a living network of neurons, and we'll develop algorithms to train it."

The team, which includes Rossin colleagues Yevgeny Berdichevsky and Zhiyuan Yan, brings together complementary expertise in computer architecture, bioengineering, and signal processing. In their project, images of handwritten digits are encoded into what are called "spike train stimuli," similar to a two-dimensional bar code. The encoding of the spike train will then be optically applied to a group of networked *in vitro* neurons with optogenetic labels. The intended impact of this work is to help computer engineers develop new ways to think about the design of solid-state machines and influence other brain-related research.

Guo says that these two projects are representative of her lab's work in exploring what's next in computing architectures and platforms.

Says Guo: "As the computing industry reaches the fundamental limits of Moore's Law and is challenged to find ways to continue innovating, we need to improve the technologies we have today—and we need to explore revolutionary ideas that will enable the forward march of progress tomorrow." 



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GRAPPLING WITH CONVERGENCE

Leaders with interdisciplinary mindsets will unlock the full potential of new tech like AI and the Internet of Things, says Bill Amelio '79 '08H '18P.

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