Spring 2021

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Engineering Innovation @LehighU

THE SCIENCE OF AUTONOMY

In Lehigh's new AIR Lab, researchers rise to the interdisciplinary challenges of Robotics 2.0

See page 10

/ A clue to COVID-19's high infection rate

/ Introducing Hawk: Lehigh's newest supercomputer

/ Strengthening infrastructure's resilience

LEHIGH UNIVERSITY | P.C. Rossin College of Engineering and Applied Science

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LEHIGH UNIVERSITY

LETTER FROM THE DEAN

Determined, focused... and moving forward

Welcome the Spring 2021 issue of *Resolve*—a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science.

Given the sheer resilience and indomitable spirit exhibited by the Lehigh Engineering community over the past year, the name *Resolve* has never been more fitting. As we reflect upon the challenges of the pandemic and the hope that dawns with this particular spring, we take great pride in all members of our learning community who went to extraordinary lengths to keep our ship on course. ("Teaching in the Time of Coronavirus," on page 22, highlights some creative faculty solutions.)

This issue also celebrates the unveiling of Lehigh's new Autonomous and Intelligent Robotics Laboratory (AIR Lab), within Building C on the Mountaintop Campus. The AIR Lab (page 10), a three-story glass cube, was made possible by gifts to the Rossin College Dean's Strategic Initiatives Fund. It is a shining example of the importance of philanthropy in opening new vistas of discovery, creation, and innovation.

Building C itself is a massive, undeniable expression of research creativity and innovation made possible by a prior transformational gift to Lehigh. The AIR Lab, carved from this space with direct support from the college's extended community, leverages this leadership into focused academic progress.

This issue's Q&A (page 8) features Elsa Reichmanis—researcher, innovator, educator, National Academy of Engineering member, and now professor of chemical and biomolecular engineering at Lehigh. Professor Reichmanis will be one of the inaugural residents of the new Health, Science, and Technology (HST) building when it opens in the fall. This state-of-the-art facility further exemplifies the significant impact of capital investment on our academic mission, catalyzing research in fields such as energy, personalized medicine, and biomaterials.

Our strategic and development priorities continue to focus on research, including facilitation of interdisciplinary faculty teams to address societal grand challenges, support for doctoral students who are central to our research productivity, and investment in facilities that are essential to advancing our research enterprise.

Our philanthropic endeavors also focus on new and ongoing efforts that guide ours to become a fairer, more open, and all-around better place to live and learn. We have launched a new Diversity, Equity, and Inclusion Fund to support, through annual giving, the success of our college's diversity plan, including targeted efforts to diversify our faculty, student body, and staff, as well as to enhance equity and inclusion throughout our community.

THE AIR LAB IS A SHINING EXAMPLE OF THE IMPORTANCE OF PHILANTHROPY IN OPENING NEW VISTAS OF DISCOVERY, CREATION, AND INNOVATION.

The Experiential Learning Fund rounds out the college's philanthropic themes. Our goal is to ensure that our students—regardless of their backgrounds or financial means—can engage in projects that help them to discover and cultivate their passions, give them opportunities to apply what they learn in their courses, and allow them to create impact through meaningful, relevant activities.

These three areas—research growth, equitable community, and experiential learning—are strategic imperatives for our college. Through GO! The Campaign for Lehigh, philanthropy has the ability to ignite real and lasting change, enabling us to realize this vision. I invite you to visit *gocampaign.lehigh.edu* to learn more and join the cause!

I hope you enjoy this issue of *Resolve*; please drop me a line with your thoughts and comments. As always, thank you for your interest in Lehigh Engineering.

Stephen P. DeWeerth, *Professor and Dean*
P.C. Rossin College of Engineering and Applied Science
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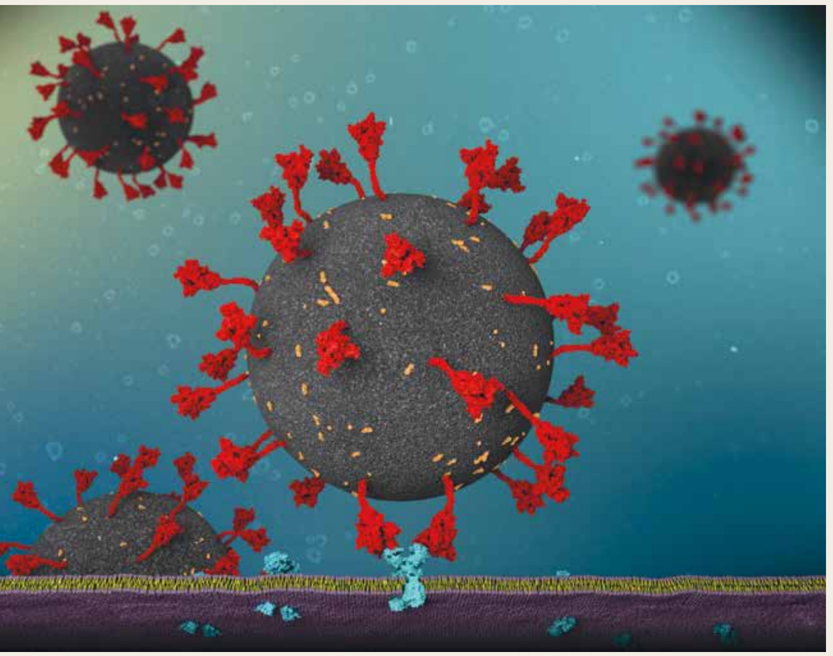
Virus-cell interaction may explain COVID-19's high infection rate

Bioengineering researchers have identified a previously unknown interaction between angiotensin-converting enzyme 2 (ACE2) receptors in human cells and the spike, or "S," protein of SARS-CoV-2, the virus that causes COVID-19. This information could aid in the development of new strategies to block SARS-CoV-2 entry into human cells.



The specific interaction between ACE2 glycans and the SARS-CoV-2 spike protein, illustrated above, makes the separation of the virus from cells so difficult, says Im.

The finding may partially explain the higher infection rate of COVID-19 compared with the similar virus that caused the 2002–2004 SARS outbreak. Lehigh professors X. Frank Zhang and Wonpil Im and their teams made the discovery using combined single-molecule force spectroscopy and molecular dynamics simulations.

"Our goal was to characterize SARS-CoV-2 and study the protein-protein interactions during its invasion of human cells to provide more insights into the mechanisms that make this first step possible," says Zhang. "After we carefully removed all of the ACE2 glycans and measured the force of the interaction, we saw that the strength of the SARS-CoV-2 spike–ACE2 interaction fell back to levels similar to SARS-CoV-1."

Their findings appear in a special issue of *Biophysical Journal*. Additional authors include Wenpeng Cao, Decheng Hou, Seonghan Kim, and Chuqiao Dong (from Lehigh), as well as Wanbo Tai and Lanying Du (from Lindsley F. Kimball Research Institute, New York Blood Center).

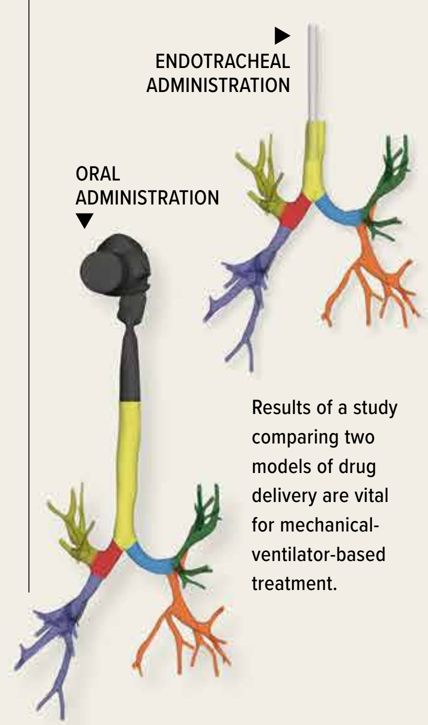
» Improving ventilator-based therapy through advanced fluid dynamics People with chronic lung diseases who are placed on ventilators may experience pulmonary conditions that are relevant to COVID-19. These patients will often receive drugs like albuterol through an endotracheal tube, a treatment that relaxes bronchial muscles and improves airflow to the constricted lung airways.

Researchers from Lehigh and the University of Arkansas for Medical Sciences recently sought to determine the most effective methods for administering albuterol via ventilator. The team members gave a virtual talk on their work during the 73rd Annual Meeting of the American Physical Society's Division of Fluid Dynamics in November 2020.

Ariel Berlinski and his group ran aerosol characterization experiments at the University of Arkansas. Rahul Rajendran, a new Lehigh PhD, used the results to investigate drug delivery through computations.

"The research objective was to evaluate the efficiency of drug delivery when the nebulizer type and its placement were varied in the ventilator circuit," says group member Arindam Banerjee, a professor of mechanical engineering and mechanics in the Rossin College.

The researchers found that a vibrating mesh (rather than a jet) nebulizer placed on the dry side of the humidifier delivers the highest dose to the lung. Administering albuterol through intubation works most effectively for smaller particles, while oral administration is more efficient for larger particles.



Results of a study comparing two models of drug delivery are vital for mechanical-ventilator-based treatment.

» Examining pandemic health toll with multidisciplinary lens Researchers from all five of Lehigh's colleges are studying the physical and mental health impact of the COVID-19 pandemic on the Lehigh Valley community. The team, which is led by College of Health associate professor Fathima Wakeel, includes Karmel S. Shehadeh (pictured),

an assistant professor of industrial and systems engineering, who brings experience in operations research and analytics in health care delivery.

The community study focuses on vulnerable populations (including racial/ethnic minorities and people with chronic conditions) and demographic characteristics such as pre-pandemic individual/family health status, pandemic-induced economic and social stressors, and the ability to follow social distancing guidelines. The results are expected to provide novel insights into the mechanisms by which potential predictors of health are related to short-term local effects of the pandemic, as well as the longer term impacts at the state and national levels.

Shehadeh will use advanced methods to analyze the data and build models that help make sense of the pandemic's health repercussions. "We can leverage what we learn from this pandemic to design data-driven policies and strategies to lead health care transformation to better prepare for future health challenges," she says.

TOP: ILLUSTRATION BY YEOL KYO CHOI; BOTTOM: ILLUSTRATION BY RAHUL RAJENDRAN

Shaping up: The future of fusion power

Project at NSTX-U will contribute to the eventual design of energy-producing tokamak reactors

Schuster describes his project at NSTX-U (above) as a "mix of plasma physics and control science work."

How will the future of fusion-powered nuclear energy take shape?

It could boil down to a question of apples versus donuts.

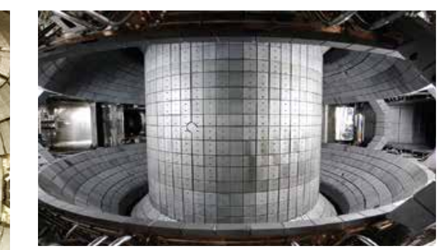
For engineers trailblazing toward the still-long-off goal of a sustainable, safe, and economically feasible fusion reactor, the choice represents two different design approaches to tokamaks, the giant devices used to study the behavior of fusion plasmas.

"Conventional tokamaks, like the DIII-D National Fusion Facility here in the U.S. or KSTAR in South Korea, have a toroidal, or donut, shape," says mechanical engineering and mechanics professor Eugenio Schuster.

Spherical tokamaks, such as the National Spherical Torus Experiment Upgrade (NSTX-U) at Princeton Plasma Physics Laboratory (PPPL), "while still technically a donut shape, have a very small hole in the middle," he explains, "so they look more like a sphere." (Visualize a cored apple.)

Schuster leads Lehigh's Plasma Control Group, which has been awarded more than $1.5 million from the Department of Energy to conduct research at NSTX-U. The work will help physicists answer key questions about the spherical tokamak concept and contribute to the eventual design of a compact, efficient fusion reactor.

Tokamaks confine a plasma—the same superheated electrically charged gas where nuclear fusion takes place in the sun and the stars—within magnetic fields. This "invisible bottle" prevents the plasma (at around 100 million degrees Celsius) from touching the inner wall of the tokamak. In present tokamak "devices" like DIII-D and NSTX-U, researchers study the physics of the plasma while avoiding a significant amount of nuclear reactions that would generate undesirable levels of radioactivity. Understanding the dynamics of this plasma will enable the development of tokamak "reactors," where energy generation will be the goal.



APPLES VERSUS DONUTS: TOKAMAKS FOLLOW TWO DESIGN APPROACHES—**SPHERICAL** (LEFT) AND **TOROIDAL** (ABOVE)

NSTX-U is coming back online following a shutdown caused by a malfunctioning magnetic coil in 2016, when it was resuming operations after a four-year upgrade. Schuster is confident in the re-engineered device and looks forward to using its upgraded capabilities to explore the possibilities of the spherical tokamak geometry.

"For Lehigh to be part of this relaunch, it is an honor for us," he says. "And we're very excited about what this machine will be able to do."

One of the priorities for NSTX-U, Schuster says, "is to get 'advanced plasmas,' which have greater stability and can work longer in a steady state, or without the help of inductive means of current. They have high performance, in terms of pressure. The higher the pressure, the more efficient the nuclear fusion reaction will be."

Schuster and his multidisciplinary team will develop models to better understand the dynamics of these types of plasmas and write physics-based codes to predict their behavior. The models will lead to the design of control strategies to effectively regulate the plasma in closed loop.

The collaboration will include Tariq Rafiq (principal research scientist in the mechanical engineering and mechanics department), grad students, and a postdoc, along with one of Schuster's former PhD students, Mark Daniel Boyer, a staff research scientist at PPPL.

As a Scientist Fellow in Plasma Control for ITER (the world's first nuclear reactor based on fusion, currently under construction in France), Schuster is part of the effort to get that facility operational by 2025. It will likely take another 10 to 15 years to produce energy from fusion at the reactor's intended target.

His experiments at NSTX-U take an even longer view: "If we demonstrate that there are benefits, the next reactor might use this more compact, spherical configuration that we intend to explore at PPPL."

TOP AND CENTER LEFT: ELLE STARKMAN/PPPL COMMUNICATIONS; CENTER RIGHT: KOREA INSTITUTE OF FUSION ENERGY

In sight: A paradigm shift in materials characterization

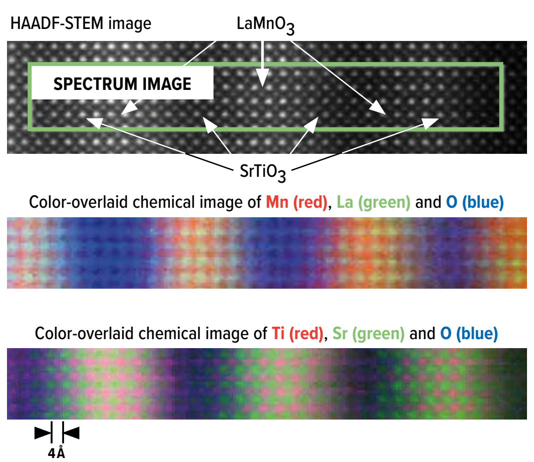
Novel instrumentation could give scientists a clearer picture at the nanoscale level

Lehigh researchers are transforming an aberration-corrected scanning transmission electron microscope (STEM) into the equivalent of a synchrotron facility (a football-field-size particle accelerator), with greatly improved spatial resolution and versatility.

This upgraded instrumentation system, which integrates an electron energy loss spectrometer (EELS) into the aberration-corrected STEM (a 3-meter-tall instrument housed in Whitaker Lab) would expand scientists' ability to characterize the chemical composition and bonding status of elements within a material down to the single-atom level, says Masashi Watanabe, an associate professor of materials science and engineering.

> "THIS SYSTEM WILL GIVE LEHIGH A **UNIQUE** CAPABILITY IN MATERIALS CHARACTERIZATON RESEARCH."
>
> —Masashi Watanabe

In electron energy loss spectrometry, a thin sample of a material is hit with the powerful electron beam of an electron microscope. The EELS measures the changes in kinetic energy of electrons as they interact with the sample, which allows scientists to determine the elemental composition and to interpret chemical bonding status of materials. The technique is an alternative to synchrotron-based x-ray absorption spectrometry, but current implementations at large-scale facilities can't offer information at the nanoscale.



Images produced using EELS, like this example, help scientists better understand elemental distributions within materials at the atomic scale and interpret their chemical bonding status.

"Even at the national labs' powerful synchrotron facilities, there is no instrument that can get this high spatial-resolution information, this level of detail at the nanoscale, that we're targeting," says Watanabe. "With a successful prototype that meets our goal of increasing spatial resolution by 1000 times over current integrations, we see important applications in areas like semiconductors, advanced alloys, and catalysis—and the potential for an overall paradigm shift."

It's an advance that could usher in a new era in materials characterization.

The team is partnering with Japanese electron microscope manufacturer JEOL and German electron optics company CEOS to create the prototype. It will include an EELS spectrometer with improved optics design for the detection of higher energy-loss electrons and an ultra-high-sensitivity electron detector for limited signal detection in the high-energy-loss range. Current EELS spectrometers cannot detect energy-loss electrons higher than 3,000 eV; the new system will have capabilities up to ~13,000 eV.

The system will include a multifunctional scan generator for flexible electron probe control. The Lehigh team will also develop an integrated software platform to efficiently control data acquisition while maintaining high spatial resolution and allowing energy-filtered imaging. Watanabe expects to gather elemental distributions at the atomic scale (as shown in the example, at left, of electron energy-loss images from a complex oxide multilayer sample) once the system development is completed. This instrument controlling scheme has been developed through the Presidential Nano/Human Interface Initiative led by Martin Harmer, Alcoa Foundation Professor of Materials Science and Engineering.

The project was awarded a three-year, $625,000 grant from the NSF's Major Research Instrumentation Program. Watanabe, who is one of the organizers of the Lehigh Microscopy School, is leading the system's development. Fellow faculty members Helen Chan, Himanshu Jain, John DuPont, and Christopher Kiely are co-PIs on the project and will test the instrumentation in their various research areas. The proposal was coordinated through Lehigh's Institute for Functional Materials and Devices (I-FMD).

"We'll be able to expand the materials we can investigate through EELS analysis to include, for example, gold nanoparticles in catalytic applications, high-entropy alloys with heavy elements, and rare-earth-based LEDs," Watanabe says. "It will give Lehigh a unique capability in materials characterization research."

THIS PAGE: FIGURE: RESULTS OBTAINED IN COLLABORATION WITH JEOL; PHOTO BY RYAN HULVAT; OPPOSITE PAGE: COURTESY OF THE INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

Lehigh signs student, faculty exchange pact with IIT Bombay

Lehigh has established a new partnership with the Indian Institute of Technology Bombay that will facilitate academic and student exchanges, as the university continues its efforts to grow and expand international opportunities for both faculty and students.

Founded in 1958, IIT Bombay is a globally ranked technical and research university in Powai, a northern suburb of Mumbai, India. Among its academic divisions are departments focused on aerospace, chemical, civil, electrical, and mechanical engineering.

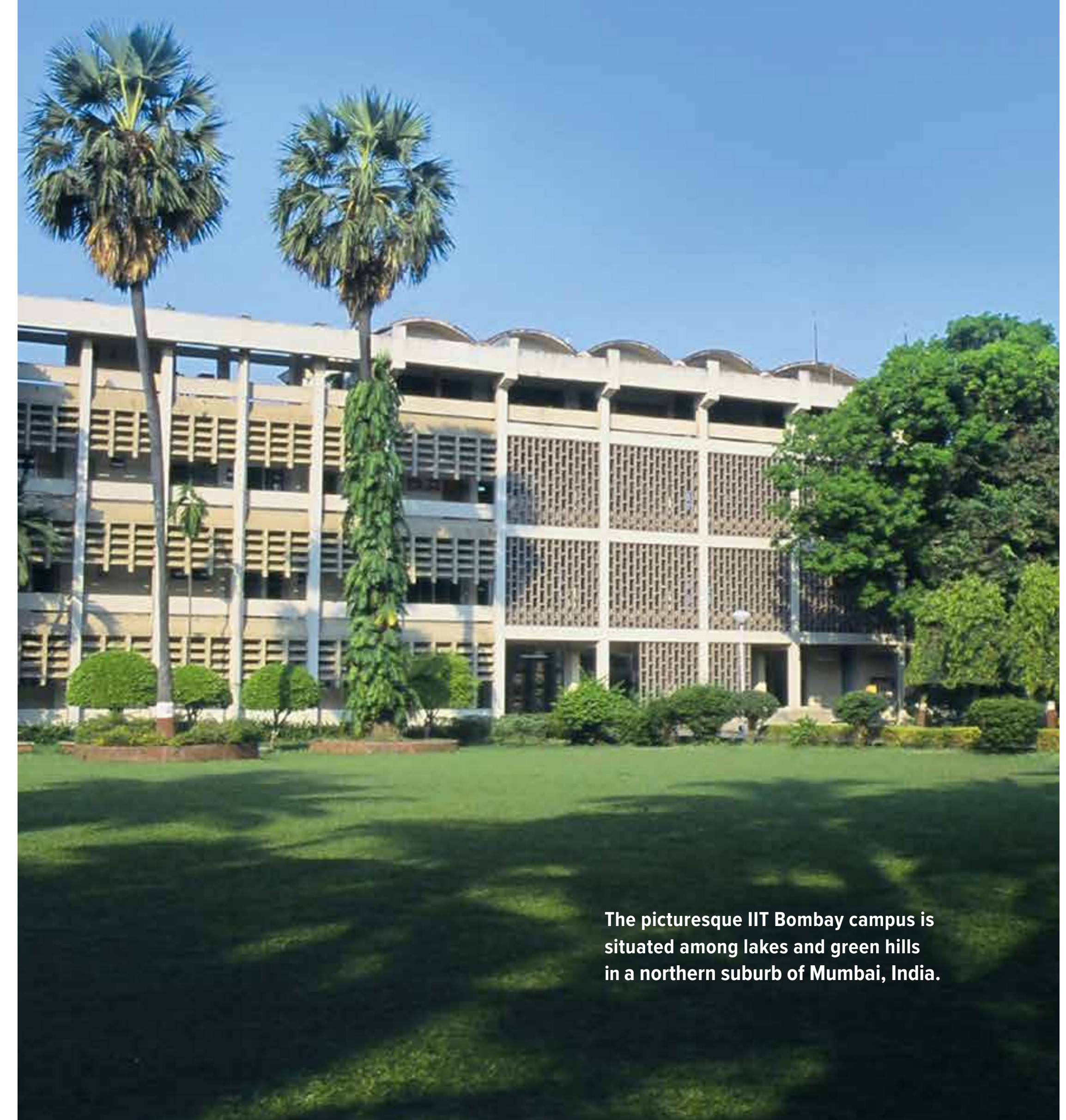
Seeds for the partnership were planted by Mayuresh V. Kothare, the R. L. McCann Professor and Department Chair of Chemical and Biomolecular Engineering at Lehigh, who graduated from IIT Bombay in 1991 and received its Distinguished Alumnus Award in 2020.

The agreement will allow for the sharing of best practices and expertise in engineering and technology. Participating students and faculty from Lehigh and IIT Bombay will come together for joint studies, research and training activities, and other educational programs.

Potential areas of opportunity include molecular modeling and catalysis, civil and structural engineering, microscopy and materials science, industrial engineering, and technical entrepreneurship.

The partnership sets the stage for a joint degree program and cooperation with the IIT Bombay Research Park.

As Lehigh broadens its global reach, says Provost Nathan Urban, IIT Bombay will be an important partner, given the quality of its programs and the reputation of its graduates.



The picturesque IIT Bombay campus is situated among lakes and green hills in a northern suburb of Mumbai, India.

JAGOTA TAKES ON COLLEGE OF HEALTH ROLE

Anand Jagota, a professor in the departments of Bioengineering and Chemical and Biomolecular Engineering, has been appointed associate dean of research for Lehigh's College of Health.

"Professor Jagota's experience founding the bioengineering department, his robust research agenda, and his connections across the colleges and with health care, industry, and federal funding agencies will enable the College of Health to rapidly and thoughtfully grow our research enterprise," says Elizabeth A. Dolan, interim dean of the College of Health.

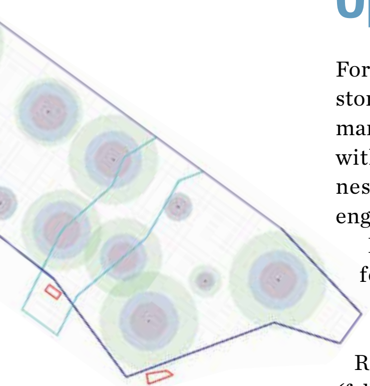
The newest of Lehigh's five colleges welcomed its inaugural class during the 2020–2021 academic year. It is the first in the nation to offer an undergraduate and graduate degree in population health with a focus on health innovation and technology.

Jagota has conducted research in biomaterials, biomechanics, and nanobiotechnology since joining Lehigh in 2004. He retains his academic appointment with the Rossin College while taking on this new administrative role.

In his new post, Jagota will advise faculty about research opportunities, connect them with investigators working in similar areas across the university, and lead the development of external research partnerships with health care and other relevant industries and nonprofits. His appointment will also help support and grow collaborations between the two colleges, extending opportunities for interdisciplinary research.

"There is already a lot of high-quality health-related research at Lehigh," Jagota says. "It is scattered in the colleges and so is less visible than it should be. The College of Health can play a role as a coordinating hub, firstly by developing top-notch research programs in chosen areas, and secondly, by building collaborative bridges with ongoing and new programs both within Lehigh and with selected external partners."

Optimizing ammunition support

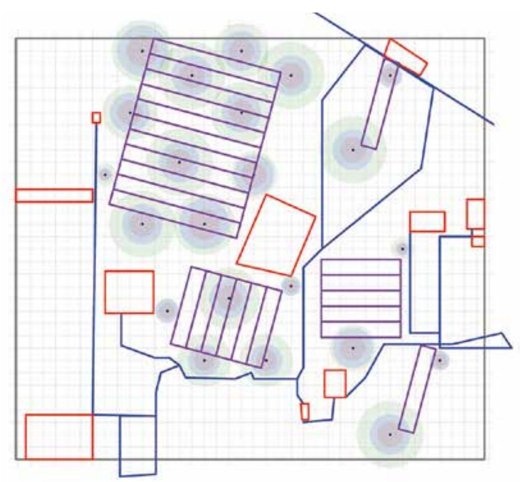


The team will create algorithms to automate the positioning of ammunition facilities during Army field operations.

For the U.S. Army, figuring out where to locate ammunition storage facilities in an area of operations is currently a manual, time-consuming, and labor-intensive process—with little guarantee of the ultimate quality and effectiveness of the design, according to industrial and systems engineering professor Robert Storer.

In short, he says, "it presents an ideal opportunity for automated optimization algorithms."

Storer and a team of Rossin College researchers (fellow industrial and systems engineering professor professors Larry Snyder and Luis Zuluaga, computer science and engineering professor Michael Spear, and ISE PhD student Ruby Zhuo) have seized the opportunity: With support from a three-year, $264,000 Army grant, they are building algorithms for automating the design of layouts for ammunition support activities.



The main focus is the positioning of field-based ammunition supply points (ASPs) and ammunition transfer points, facilities that need to be designed and built expediently during field operations. Because of their explosive contents, the facilities must be located at safe distances from each other, as well as from roads, buildings, and other vulnerable sites.

The Army's existing process, Storer says, relies extensively on the experience of ammunition chief warrant officers. Aided by mapping and graphical software, the designer plans the ASP layout by locating the various facilities on a map, observing the flaws in the design, and then reconfiguring it in a manual, trial and error procedure.

The team will automate the process by creating algorithms that will position ASP facilities in a design that optimizes the area used, he explains, while adhering to minimum distance requirements, set by the Department of Defense, within an appropriate measure of risk.

Patent propels PhD student into Army research post

Estimating a potential eavesdropper's methods of detection is a particularly challenging aspect of wireless security research, says Perazzone (above).

"It's not often that a PhD student is awarded a patent before he graduates," says Rick Blum, Lehigh's Robert W. Wieseman Professor of Electrical and Computer Engineering.

For Jake Perazzone '17G '20 PhD, the accomplishment—marking a potential breakthrough in wireless communication security—came in August 2020, exactly a day before his dissertation defense as a doctoral candidate in electrical and electronics engineering.

"Talking about my practical research at [the U.S. Army Combat Capabilities Development Command Army Research Laboratory] and my experience going through the patent process helped me defend my PhD case," he says. "I could show that I turned theory into practice."

Blum connected Perazzone with the ARL lab in 2015, recommending him for an internship at the facility before he entered Lehigh. He interned there each year during his PhD studies, often supported by the Army Research Office.

During his graduate studies, working with Blum and Army researchers Paul Yu and Brian Sadler, Perazzone proposed a streamlined model for digital security.

A secure wireless communication traditionally requires authentication (a guarantee of the transmitter's identity), covertness (a guarantee that the message remains unknown to outside parties) and secrecy (a guarantee that no third-party eavesdropper could decode the message). Typically, these are handled separately through methods such as encryption.

Perazzone and his team have learned to combine these aspects of security. Through minor perturbations in a transmission's physical waveform, a transmitter and a sender can ensure that a given transmission is both legitimate and private. A set of "signal keys"—distinct disturbances previously agreed upon between the transmitter and the receiver—determines if the message is secure. The result is a streamlined system that's faster and less susceptible to eavesdropping.

Their novel process can provide security by itself, or be added to existing methods of security, according to Perazzone and Blum. It has potential applications in both military and civilian wireless communication technology—from the most high-stakes of field transmissions to the mere remote preheating of a smart oven.

Today, with a patent under his belt, Perazzone continues to thrive at ARL. As an electronics engineer, he's helping develop cutting-edge technology, while continuing to study authentication, as well as the role of machine learning in detecting cyberattacks and deceiving adversaries.

TOP: ILLUSTRATIONS BY YIHE (RUBY) ZHUO; BOTTOM: JASON EDWARDS/U.S. ARMY RESEARCH LABORATORY

Predictive design approach borrows from birds

Hybrid 'Cuckoo Search' accelerates computational modeling of complex alloys

A major roadblock to computational design of high-entropy alloys has been removed, according to engineers from the Ames Laboratory at Iowa State University and the Rossin College, thanks to an enhanced algorithm that radically reduces the search time used for predictive design.

Existing tools for creating random distribution of atoms in materials simulation models are resource intensive, outdated, and limited in their reach for fast model generation, says Ganesh Balasubramanian, an associate professor of mechanical engineering and mechanics at Lehigh. And, even with supercomputing advances, he explains, the time required to generate robust models for materials simulations is prohibitively long.

The team's goal was to accelerate the computational modeling of complex alloys. They did this by developing a hybrid version of an algorithm called the Cuckoo Search (inspired by the evolutionary strategy of Cuckoo birds) to find the most viable "egg," or solution, within a huge set of possibilities.

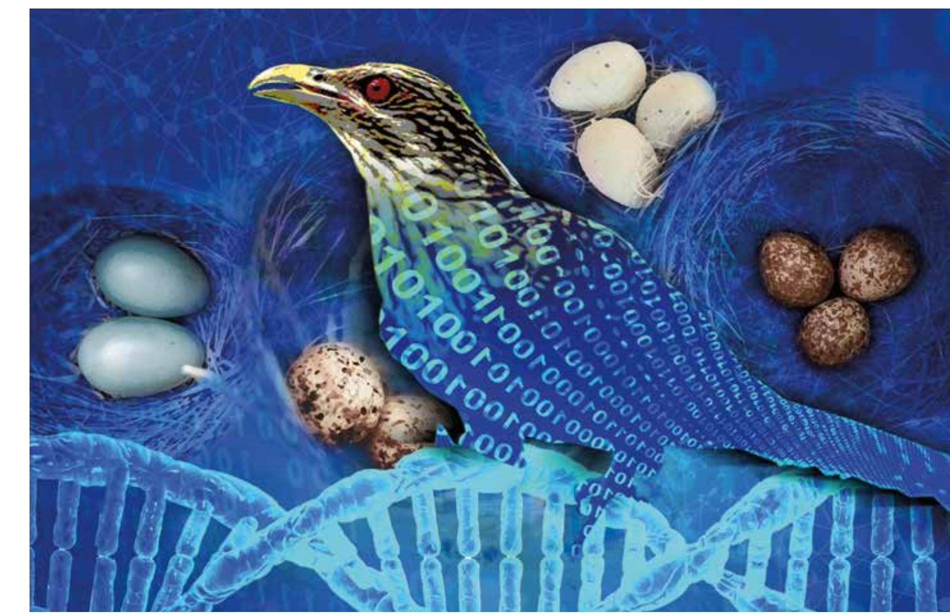
"The speed up to solution time was not surprising, but the factor reduction in time—13,000-fold—was indeed startling," says Balasubramanian. "What took about a day to accomplish, can now be done in seconds. This tool also enables creation of physically realizable systems that now can be directly compared against experimental samples."

The research, which is supported by the Department of Energy and the National Science Foundation, is described in a paper recently published in *Nature Computational Science*.

High-entropy alloys are formed by mixing equal or relatively large proportions of five or more elements. Balasubramanian works specifically with multi-principal element alloys, which are formed by mixing significant and varying proportions of multiple elements.

Preliminary studies have shown that multi-principal element alloys have superior mechanical strength and hardness, making them ideal as a protective coating on turbine blades, medical implants, ship surfaces, and aerospace parts.

"The purpose of our work on this was to optimize alloy design and, due to the results, we hope it will change design practices in materials for the better," Balasubramanian says. The computational tool may also have applications in any field that requires optimization, he adds, including stock markets, commerce, and engineering systems design.



AMES LABORATORY/U.S. DEPARTMENT OF ENERGY

INDUSTRY IMPACT, SCHOLARLY LEADERSHIP IN MATERIALS SCIENCE

RESEARCH RECOGNITION

» Meeting challenges in materials processing

WOJCIECH Z. MISIOLEK, Loewy Professor and Chair of the Department of Materials Science and Engineering (MSE) and an expert in aluminum metal forming, received the 2020 William Hunt Eisenman Award from ASM International. The award honors "unusual achievements in industry in the practical application of materials science and engineering through production and engineering use" and is typically given to industry professionals. Misiolek is one of few specialists from academia to earn the recognition, which highlighted the "technology transfer of his engineering science knowledge to industrially relevant materials processing."

Working with industry partners, Misiolek and his graduate students develop tools that address industrial challenges. His efforts in physical and numerical modeling of materials processing involve physical metallurgy and materials characterization and have applications in structural materials, biomaterials, and materials for energy. He also directs Lehigh's Loewy Institute, which researches applications of metals with an emphasis on international collaboration.

» A lifetime of contributions to glass science research

HIMANSHU JAIN, T.L. Diamond Distinguished Chair in Engineering and Applied Science and MSE professor, won the highly prestigious 2020 N.F. Mott Award, sponsored by the *Journal of Non-Crystalline Solids* (JNCS). It is granted once every two years to a senior scientist who has provided extensive and impactful contributions to glass science over the course of a career in research.

Jain has "contributed extensively to understanding the electrical properties of glasses, chalcogenide glasses, bioactive glasses, and laser-induced crystallization. He stands among the twenty most prolific researchers of the glass community and is also one of the five most active authors of the JNCS."

Jain is a founding director of Lehigh's Institute for Functional Materials and Devices (I-FMD), which pursues new materials and innovative devices that underpin grand challenges.

STEPHANIE VETO

BUILDING COLLABORATION

Microlithography pioneer Elsa Reichmanis shines light on the role of interdisciplinary research in advancing technology and sustainability

World-renowned polymer chemist Elsa Reichmanis joined the Rossin College in 2020 as Professor and Carl Robert Anderson Chair in Chemical Engineering, following 12 years at the Georgia Institute of Technology. Prior to entering academia, Reichmanis was a researcher at AT&T Bell Laboratories, where she played a foundational role in microlithography, a field central to the manufacturing of electronic devices. Over almost three decades at Bell Labs, she contributed to 20-plus U.S. patents for innovations that helped drive the personal computer revolution. Today, her research at the interface of chemical engineering, chemistry, and materials science continues to draw accolades. Reichmanis is a member of the National Academy of Engineering and was recently elected as both a Fellow of the American Institute of Chemical Engineers and the National Academy of Inventors.

Q: What is microlithography and how has your work advanced the field?

A: Microlithography uses “resist materials” to define the circuit patterns on the silicon memory chips that drive computers and cell phones—and just about every electronic device. It’s a process with roots in traditional lithography, where you might scrape a pattern with a knife into a stone surface, cover it with grease, and then transfer that pattern to a piece of paper or parchment. Microlithography is very similar but on a much finer scale. Related processes can be used in broader photonic devices, optoelectronic devices, and the large communication switches that enable internet communications.

The challenge with silicon has been that the feature size—sort of like the wiring—has continually become smaller. When I started at Bell Labs, there was interest in using shorter wavelengths of light to pattern these features, which would enable much higher resolution. So we looked at different chemistries for photopolymers that could be coated on the silicon substrate, essentially developing the “grease” that would allow us to create, on a nanometer scale, a wiring diagram for a silicon circuit.

My contribution was investigating the photochemistry—identifying approaches to developing polymer materials that respond to light and defining the requirements needed in a photopolymer, or resist, to achieve the desired performance.

Q: How has microlithography influenced the development of modern electronics?

A: We certainly take cell phones and laptops for granted. Even email and social networking rely on the circuitry in our electronics. And those devices didn’t come about just because one person had an aha moment. It took many people with varying expertise addressing different pieces of the puzzle. The silicon circuit memory device in your phone or computer today has probably more than 30 different layers of materials. All of them need to be deposited and patterned with precision. To make these chips work and continually improve the technology requires many different disciplines coming together, communicating, and learning from each other.

Reichmanis will set up her lab in the Health, Science, and Technology building (under construction in the background), a state-of-the-art facility designed to spark multidisciplinary research endeavors.

Q: Was that your experience working at Bell Labs?

A: The environment was interactive, and everybody’s door was open. We were all together, not in separate buildings, and if you had a question, you’d just find the expert to go ask. We frequently got together for lunch or morning coffee, just to chat. Someone would throw out a question or an idea, and those conversations led to chemists working with physicists working with electrical engineers, and so on.

Q: So the breakthroughs of that time were driven by interdisciplinary collaboration?

A: That’s exactly what the development of technology requires. With diversity of perspectives and a variety of expertise, you can create something new that can benefit the world. I joined Bell Labs when I was just a kid, and this was the environment that I grew up in. And in the short time I’ve been at Lehigh, I’ve become involved in a few proposals, and I’m already seeing the interactive culture that exists here. Collaboration is seen as a good thing, and that will allow our research to have a positive impact on society.

Q: What research problems are you currently investigating?

A: I’m exploring large-scale processes that can be made more cost-effective and sustainable. Can we use less material and waste less? Can we go into additive manufacturing processes? To do that, we need better understanding of the role surfaces play and how we can manipulate their characteristics to improve their properties from an electronic or optical perspective that could be useful in a device.

I’m also interested in whether we can manipulate surface chemistries so they behave in a more biocompatible way. Could a combination of electrical transport and ion transport mimic the transmission of information through synapses along nerves? Could we design an integrated artificial limb or repair nerve damage using a synthetic material that is truly biocompatible? I’m not a biomedical or electrical engineer, but by building a community of researchers who share these interests, we may be able to work together to find answers.

Q: You mentioned the concept of sustainability. What role does that play in your research involving batteries?

A: Battery technology is a key aspect of improving the energy storage landscape. If you put solar cells on your roof, they’re useful only if the sun is shining, unless the excess energy can be stored somewhere. An effective battery storage system would allow energy generated on a sunny day to be used at night or when it’s raining.

LEFT: ROB FELT/GEORGIA INSTITUTE OF TECHNOLOGY; CENTER: STEPHANIE VETO; RIGHT: ILLUSTRATION BY HGA

We’d like to have lighter weight storage systems with greater capacity that recharge more reliably. To do that sustainably, we need to think about materials: Can we limit the rare-earth materials used in storage systems or design new systems that use more abundant materials?

Also, from the device standpoint, not everything needs to have the computing power of silicon technology, which is pretty energy intensive and uses subtractive processes that generate waste. Maybe we can develop polymer or hybrid materials that would be suitable for some devices. There’s also the potential to develop platforms using carbon-based or biomass-derived materials that can be processed in an additive way.

Q: Your career has spanned both industry and academia. How do you advise students considering which path to take?

A: Particularly for graduate students, doing an internship, whether in industry or at a national lab, is a valuable way to see the different mindsets and approaches. Academic research is more open-ended. In some ways, you don’t have to make hard decisions about stopping projects or starting new ones. In an industrial environment, you are more driven by a tangible end result that provides a return on investment.

Students strongly interested in academia should examine how they feel about teaching and training students, both in the classroom and as an advisor. I typically have several undergrads in my group, and my grad students work with them to gain mentoring experience. It’s not that one path is better than the other, they’re just different. Get that internship experience, and then think through what is it that drives you, recognizing that it may change over the course of your career.

Q: What are you looking forward to about getting back to more normal campus operations?

A: I’m excited to interact more directly with my colleagues and students, and I look forward to getting my lab built and established. When HST [Lehigh’s Health, Science, and Technology building on the Asa Packer Campus (illustrated above)] is completed later this year, it will create a fantastic environment for building multidisciplinary research programs. Having a more open area where students and faculty can run into each other is exciting. I think it’s going to lead to a lot of new ideas, novel research, and exciting results.

The new AIR Lab facility—a towering glass cube in Building C—opens doors to new collaborations among robotics researchers, including Nader Motee (standing).

STORY BY RICHARD LALIBERTE | PHOTOGRAPHY BY RYAN HULVAT/MERIS

THE SCIENCE OF AUTONOMY

Robotics 2.0 depends on interdisciplinary solutions to the challenges of self-governing machines

IN BUILDING C on Lehigh's Mountaintop Campus, a new facility has taken shape. With a high ceiling and transparent glass walls, it's a hive of sorts, enclosed partly as a way to dampen the whir, hum, and drone of robots operating both on the ground and in the air. Welcome to the new, pulsing core of the Autonomous and Intelligent Robotics Laboratory (AIR Lab).

Impressive as the lab looks, its concentration of machines and support infrastructure, such as a state-of-the-art motion capture system, isn't the lab's most important feature. Even more valuable is its concentration of brainpower. "The new lab puts researchers together where they're interacting and leveraging knowledge," says Jeffrey Trinkle, P.C. Rossin Professor and Chair of the Department of Computer Science and Engineering (CSE). "There's tremendous potential for collaborative research across a wide variety of areas."

Among those rubbing elbows in the lab will be groups from CSE, mechanical engineering, electrical engineering, industrial engineering, and other disciplines affiliated with Lehigh's Institute for Data, Intelligent Systems, and Computation (I-DISC). Together, multiple researchers approaching from different angles will use the lab to attack some of the most vexing problems in a field that's both inherently interdisciplinary and central to the future of robotics: the science of autonomy.

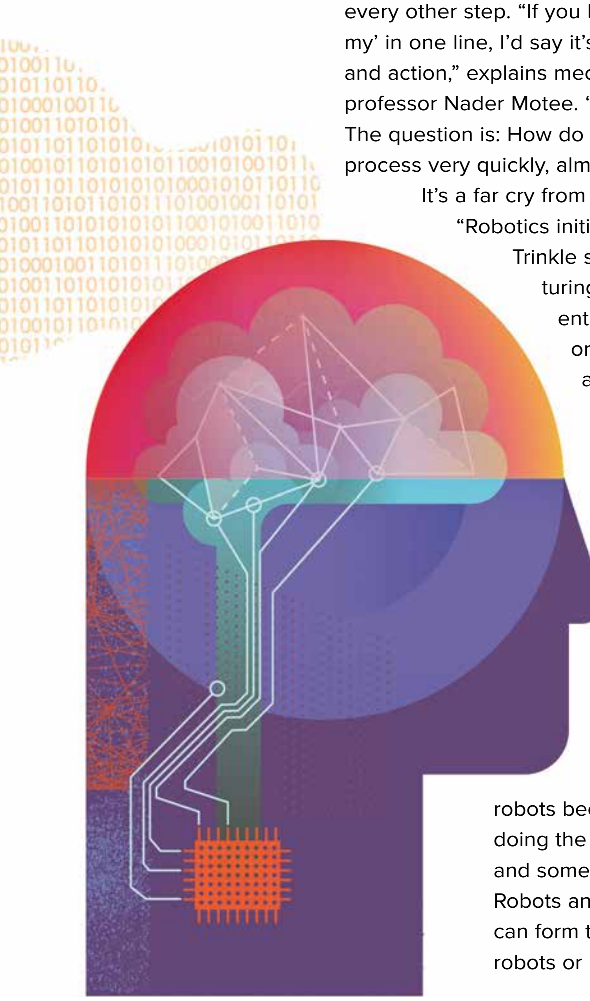
FROM SENSING TO ACTION

The idea that human-made objects might operate independently, if not think for themselves, has roots in ancient myths and legends, but it began finding modern expression with the origin of the word "robot" in *R.U.R.* (*Rossum's Universal Robots*), a famous 1920 science fiction play by Karel Čapek. It created the mold for every fictional semi-sentient machine you've encountered on screens or pages ever since.

"**ROBOTICS 2.0** IS TO HAVE ROBOTS AND HUMANS **COEXIST** AND EVEN **CO-WORK EFFECTIVELY**." —Jeffrey Trinkle

But it's exponentially easier to imagine an anthropomorphized, mechanical Robby, Rosie, or C-3PO than it is to create an actual machine that can sense its environment, gather data, pick out the most relevant details, infer some form of meaning, come to conclusions, make decisions, form plans, and execute tasks.

Each of those steps is critical to successful autonomy. And each presents challenges interrelated with challenges posed at every other step. "If you had to define 'the science of autonomy' in one line, I'd say it's closing the gap between sensing and action," explains mechanical engineering and mechanics professor Nader Motee. "Humans do this easily and constantly. The question is: How do we make a robot understand the entire process very quickly, almost in real time?"



It's a far cry from what robots have done in the past. "Robotics initially evolved to hard automation," Trinkle says. "Think of the old-style manufacturing assembly lines where you had different stations with a machine made to do one particular job efficiently, accurately, and many, many times over." People generally were kept apart from working robots partly out of concern that automation could prove dangerous if a human inadvertently got in a machine's way.

In recent years, research initiatives such as a key program from the Office of Naval Research have sought to nudge robots toward more versatile capabilities. "Robotics 2.0 is to have robots and humans coexist and even co-work effectively without danger to people," Trinkle says. "The robots become more capable of thinking and doing the right thing at the right time in harmony, and sometimes in collaboration with humans. Robots and people do what they're best at and can form teams that perform better than either robots or humans could by themselves."

Self-driving cars and package-delivering drones are two of the most familiar prospective applications of advanced robotic technology. But future uses could far exceed those visions. At Lehigh alone, researchers foresee their work potentially being used in areas as diverse as search and rescue, agriculture, construction, space missions, structural repairs, biotechnology, disaster response, environmental cleanup, surveillance, and even parking-space allocation.

"The goal is to have versatile machines that can accept high-level commands and then do jobs by themselves," says David Saldaña, an assistant professor of computer science and engineering. "An important part is what we do behind the scenes with mathematical models, algorithms, and programming."

CONTROLLING COMPUTATION

At the front end of the sensing-to-action progression, robots need to perceive their environment. "That's a challenge right there," Motee says. "How will they process all that information?" Streaming images from an onboard high-frame-rate camera might provide up to 1,000 frames per second from a single robot, each frame packing four or five megabytes of data. One second later comes another data dump potentially as big as 5,000 megabytes. In multi-agent networks of robots such as drone swarms, this information might be passed between individual units. "If they're sharing raw information from each frame, that's extremely costly in terms of processing," Motee says. "We need preprocessing of only relevant information."

Motee is developing such data-parsing capabilities in a map classification project. Suppose, he says, a group of drones is dropped into an unknown environment—say, one of 20 possible college campuses—and it's up to the robots to figure out where they are. Motee is working on methods for each drone in a distributed network to focus only on features and landmarks relevant to whether they're at Lehigh, Princeton, or somewhere else and to share that information optimally through the network.

ILLUSTRATION: DRAFTER123/ISTOCK

Similar parsing could be used with a robot faced with a task that any human would find easy: getting up from a sofa and walking into the kitchen. A coffee table between the sofa and door would be mission-relevant because the robot must navigate the obstacle. "But it doesn't matter if there's a laptop on the other side of the room, because it has nothing to do with the mission," Motee says. "The goal is mission-aware feature extraction."

One way to extract relevant features is to employ machine learning based on pattern recognition. If you step in front of a self-driving car, its system must conclude that what it "sees" is human before making decisions, forming plans, and taking action—e.g., slamming on the brakes. "Modeling the shape of a human and how one moves based on physics is extremely hard," Motee says. "So we don't write an equation for the dynamics of the human body. We train the machine with lots of samples from the human body and it learns what a human looks like without caring too much about exact parameters." The robot doesn't need a precise description of every person alive. It can extrapolate learned patterns to objects it hasn't seen before and recognize that you belong to the same group as a man using a walker or a child chasing a ball.

Other tools that can help robots make decisions, plan actions, and work with other robots are based on logic that also captures events over time—temporal logic. Missions and rules described in temporal logic are automatically transformed into plans for the robots to follow, and are guaranteed to be safe and correct by construction. These techniques belong to the engineering field of "formal methods."

"Using temporal logic, we can say something like, 'within a given time, a robot will arrive at Site A to extract a sample, and at Site B to extract a different sample, and upload them at Site C, while following safety properties such as avoiding a hazardous area,'" says Cristian-Ioan Vasile, an assistant professor of mechanical engineering and mechanics, who investigates the use of formal methods in autonomy. Such high-level instructions generally proceed in a certain logical order, though specific combinations of tasks and timelines may provide options.

Motee sees potential for both temporal logic and machine learning to guide computation in his example of a robot heading to the kitchen. If the robot had previously observed you making an omelet, "it could learn the sequence of actions you took in a specific order," Motee says. Get eggs. Heat pan. Break shells. Classical logic built on true/false statements might tell the robot that, true, each of those steps is necessary for an omelet. But the robot also needs to understand

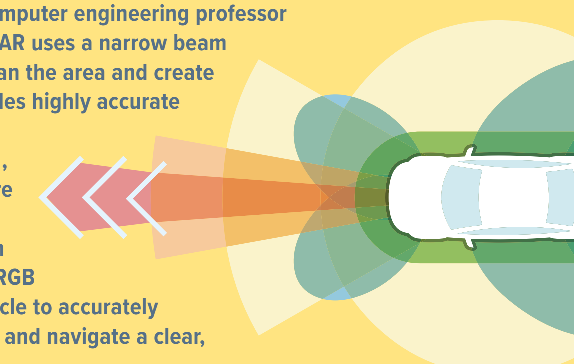
TOP: PIRANKA/ISTOCK; ILLUSTRATION: YURIY BUCHARSKIY/ISTOCK

ENVISIONING THE FUTURE OF AUTONOMOUS VEHICLES

Opportunities for experiential learning abound as faculty teach new tech, develop novel systems to control robotic vehicles

LiDAR (shorthand for "light detection and ranging") has been hailed as a game-changer in the race toward developing a truly "driverless" car, or what the Society of Automotive Engineers defines as a Level 5 autonomous vehicle (AV).

"The technology is similar to radar and sonar, in that the device sends out a pulse, which bounces back signals to detect obstacles," explains electrical and computer engineering professor Yahong Rosa Zheng. "LiDAR uses a narrow beam of light to very quickly scan the area and create a 'point cloud' that provides highly accurate range information."



Fed into an algorithm, LiDAR data—which is more manageable in size and requires less computation than what's captured by RGB cameras—allows the vehicle to accurately perceive its surroundings and navigate a clear, safe path.

Zheng recently integrated 2-D LiDAR into her hands-on, project-based course on Robotic Perception and Computer Vision, which uses the University of Pennsylvania's F1TENTH Autonomous Vehicle System and features a racing component. "Each project builds on how to program the cars," she says, "looking at different algorithms for tasks like reactive methods, path planning, and autonomous driving."

Although the pandemic forced a pivot to simulated races, students took part in a socially distanced "play day," testing out the vehicles, which are one-tenth the size of a Formula One car, in a campus parking garage.

"We're teaching students the basics of the programming involved with AVs, while giving them the chance to see that there are a lot of research opportunities in this area," she says. "Many of the companies working on autonomous driving are at Level 3 or not yet reaching Level 4," she adds. "Nothing is set in stone yet."

Zheng's assessment is borne out by research heading in the opposite direction—away from LiDAR—led by computer science and engineering (CSE) professor Mooi Choo Chuah.

In their quest for greater profitability and wider market adoption, Chuah says, makers of AVs must weigh the advantages of LiDAR against the added cost. There is also debate over whether newer RGB-D cameras (which provide depth information) combined with advances in deep learning could eventually close the gap in computer vision capabilities.

Chuah is exploring that possibility in a project funded by the NSF to develop a robust perception system for AVs, using cameras and smarter sensors, with lower computational demands. She is collaborating with Corey Montella '19 PhD, a professor of practice in the CSE department, to integrate her system into the robotic cars used in his undergraduate capstone classes to eventually provide proof of concept. *—Katie Kackenmeister*

through temporal logic that each step must be true at a certain point in time relative to other steps. Otherwise, you could have a mess instead of a meal.

"Can a robot learn these skills and express them as statements in logic? That's still a very big open question," Motee says. "But if we want robots to merge with society, they need to learn about human behavior—what actions we take and in what order."

DIVERSE APPROACHES

As robots merge with society, they'll also increasingly engage with other robots. "As we add robots, we need to plan for them," Vasile says. "It becomes a question of scalability, which is a large issue." Computational methods developed in recent years may handle interactions between handfuls of robots. "But if we want to plan for 20, 50, or 100 robots, the methods break down because there's an exponential growth in the computation needed," he says. "There's a mathematical reason for this and it's very hard to solve." One approach to solutions: "In our recent work, we use structure to simplify some of these problems," Vasile says.

Structure can refer to a robot's circumstances or environment. Rules of the road for a self-driving car have a particular structure, Vasile says, but not every rule applies to every situation. "We leverage that structure to mitigate the rules tracked at one time in order to manage computation," he says. A set of rules such as the Vienna Convention on Road Traffic, used throughout Europe and elsewhere, might have about 130 rules, "but maybe only 10 of them apply to a car at a four-way stop," Vasile says. "That can simplify planning."

The AIR Lab brings together faculty, including Vasile (above, center) and Bhattacharya (top, right), and students tackling robotics challenges from varied perspectives.

Yet some robots will need to operate in environments less structured than the open road—such as the open sea. Planning for motions in complex environments can quickly outstrip computational capacity, creating a need for abstractions that can help manage the computational load. Such abstractions can be found in topology, a branch of mathematics that analyzes the shape of configuration spaces.

"We try to understand configuration spaces in terms of their shape," says Subhrajit Bhattacharya, an assistant professor of mechanical engineering and mechanics. "This helps us abstract details of a high-degree-of-freedom system into more manageable abstractions that reduce the amount of computation necessary and also allows us to solve problems correctly."

Some of Bhattacharya's research uses topological approaches with application to motion planning for robots attached to some form of cable. Examples might include autonomous watercraft tethered to flexible booms that maneuver in tandem while avoiding collisions or entanglements with each other or various obstacles—potentially useful for cleaning oil spills at sea. Other possibilities might include self-operating vacuum cleaners with hoses attached to walls or cable-actuated factory robots. "It's difficult to plan

accurately for cables or control them," Bhattacharya says. "But if you apply topological abstractions, you can simplify problems by thinking of topological classes such as moving to the left or right of an obstacle."

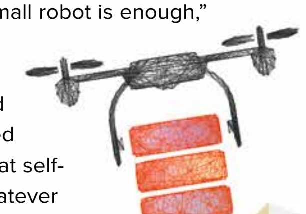
Topology also can help plan actions for systems with high dimensional configuration spaces such as the movement of a multi-segmented robot arm or—in the case of a project Bhattacharya is working on with Lehigh alumnus Matthew Bilsky '12 '14G '17 PhD, founder of a start-up called FLX Solutions—a snake-like robot that could navigate and brace itself inside walls or other hard-to-reach spaces to perform repairs or conduct inspections.

Bhattacharya points to Vasile's work as an example of different perspectives addressing similar problems. "Cristian focuses on formal methods while I focus more on understanding the topology and geometry of space," he says. "But we can put together our approaches to solve problems more efficiently."

TEAMS OF MACHINES

Ultimately, the sensing-to-action model of autonomy comes down to robots actually executing their missions. But sensing, planning, and control are just as crucial on the business end of robotics as earlier in the autonomy process. That's especially true for robots working together. "We want to build algorithms and controllers that allow robots to autonomously cooperate and behave as a unit even though they're independent," Saldaña says.

He sees teamwork as a key to the versatility Robotics 2.0 demands. Consider the prospect of drone delivery. "If you want to transport a T-shirt, a small robot is enough," Saldaña says. "If you want to transport a sofa, you need a very large robot." But instead of vast lineups of different-sized robots, he envisions drones that self-assemble in midair to form whatever configuration or size a task demands.



Potential applications go far beyond shipping your latest Amazon purchase. Imagine a high-rise fire in which stairwells have collapsed and people are trapped on floors above the flames far beyond the reach of ground-based rescuers. As the inferno rages, hundreds of drones appear like a whining flock of starlings. They split into groups, and individual robots in each formation dock together to form different structures. One group creates a fire-escape staircase on which people can clamber to a safer level. Another builds a bridge they can cross to an adjacent building. A third creates a hovering platform that ferries evacuees from windows to the ground.

Units forming in such multi-agent flying systems would, in effect, have to do what most robots are expressly instructed to avoid: collide with each other. Doing so in the gentlest, most controlled way possible poses considerable challenges, but Saldaña already has built aerial vehicles that can magnetically dock and pull apart in flight.

"It starts with modeling the system, which requires a lot of mathematics and physics," Saldaña says. Docking and undocking must consider a variety of dynamic forces including those from drone propellers' linear and rotational accelerations. "From physics and dynamics, we go to control theory—that is, a mathematical model of how a robot should behave and move—to design algorithms that we put into programming languages like C++ or Python," Saldaña says. Sensors in the robots monitor their locations and allow drones to quickly compensate for them. "The robots need to be very precise when they approach each other but also very aggressive for specific amounts of time," Saldaña says. To detach in midair, drones reach an angle of 40 degrees in less than two seconds, like a pencil snapping in two. "That is not something they would normally do," Saldaña says. The drones then rapidly stabilize.

Saldaña is now developing bigger, more powerful robots and increasing their capabilities. For example, he's used a configuration of four attached drones that rotate their corners apart to create a donut-like center space capable of closing around a coffee cup and lifting it from a stand to a trash can.

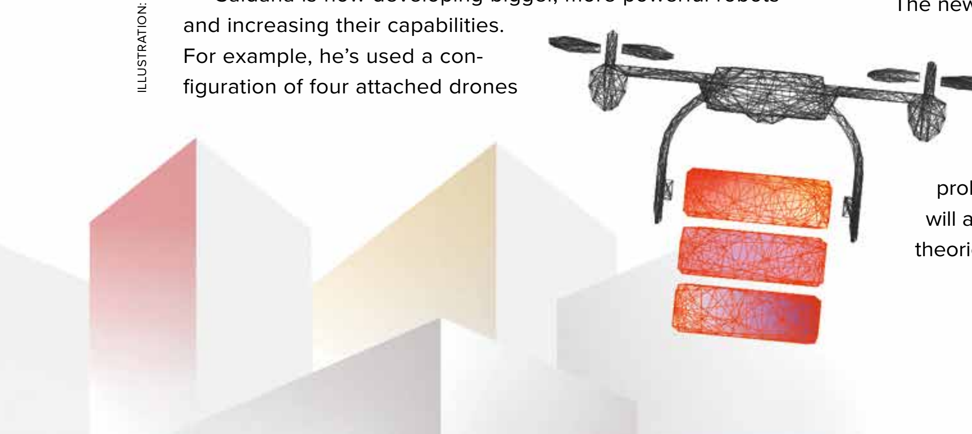


ILLUSTRATION: CHANUT IAMNOI/ISTOCK; AHA-SOFT/SHUTTERSTOCK

Being able to grasp objects opens possibilities for robots—flying or otherwise—to manipulate their environment and accomplish tasks such as repairs—a line of research in which Trinkle specializes. "If there's a cell phone on a counter and a robot wants to pick it up, it needs to touch the cell purposefully and safely without breaking itself, the counter, or the phone," Trinkle says. "It may need to slide the phone to the edge of the counter and pinch the part that's hanging over. Those kinds of contact changes where you're touching or not touching something require a human-like deftness that's tricky for a robot."

Saldaña (center) and his students will use the new facility for their work on multi-robot systems, resilient robot swarms, and modular aerial robotics.

Trinkle and a PhD student are tackling these challenges through machine learning and instruments such as tactile sensors. "We're developing capabilities that don't currently exist because researchers haven't applied these tools specifically to solve these kinds of problems," Trinkle says.

Further challenges lie in what may be described as human-robot relations. Vasile describes one area as "the explainability of AI"—that is, the ability of artificially intelligent robots to offer people comprehensible reasons for the decisions robots make. "This is very new and we don't know how to do it very well, but it will be important to any applications," Vasile says.

> "HAVING A LARGE SPACE TO DEPLOY MANY ROBOTS WILL ALLOW US TO **DEVELOP NOVEL PLATFORMS** TO EXPLORE OUR THEORIES." —David Saldaña

Another area pertains to a kind of artificial emotional intelligence. For example, a housekeeping robot might best avoid turning on when cleaning would irritate homeowners, or a workplace robot teamed with a human might be more effective if it realizes that its flesh-and-blood partner is in a bad mood or not ready. "That part of robotic perception is a step beyond what a lot of people think about," Trinkle says.

Such considerations further broaden the interdisciplinary nature of autonomous robotics. "Challenges dealing with emotion may entail collaboration with psychologists," Trinkle says. "In the nearer term, there's a lot more collaboration in store between different forms of engineering and computer science."

The new AIR Lab facility promises to accelerate multidisciplinary interactions between faculty and students alike. "It's not enough to study programming, mechanics, or mathematics separately," Saldaña says. "Real-world robotics needs to combine all these fields to propose solutions to problems. Having a large space to deploy many robots will allow us to develop novel platforms to explore our theories and perform realistic experiments."

RYAN HULVAT

LAUNCHING HAWK

BY KATIE KACKENMEISTER

New supercomputer widens access to data science tools and connects Lehigh to the global cyber infrastructure

THE NEXT PHASE of high-performance computing (HPC) at Lehigh recently took flight with the introduction of Hawk, a new research computing cluster established with a $400,000 grant from the National Science Foundation's Campus Cyberinfrastructure program.

"Developments in HPC have unlocked certain kinds of problems that were previously unaddressable," says Nathan Urban, provost and senior vice president for academic affairs. "Whether in structural engineering, genomics and health, or physics and cosmology, simulations and data-intensive research are increasingly important to the work taking place at Lehigh."

Excitement around the 34-node supercomputer goes beyond its technical specs and capabilities, according to Edmund Webb III, an associate professor of mechanical engineering and mechanics who is leading the project. (Hawk, for the record, includes 1752 CPUs, 32 GPUs, and 16,896 gigabytes of RAM—or the computing power of about 180 top-of-the-line MacBook Pro laptops plus 32 Xbox Series X or PlayStation 5 gaming consoles.)

By design, the new cluster is primarily "a leap forward in computing capacity," says Webb, and its launch is a milestone in widening access to HPC resources for large-scale simulations and other data-heavy operations.

The added capacity will also allow Lehigh to join the Open Science Grid, a national distributed computing partnership for data-intensive research in fields such as high-energy physics, and, recently, in the study of COVID-19.

"The OSG allows institutions to 'donate' their idle CPUs," says Alex Pacheco, Lehigh's manager of research computing and a collaborator on the grant (along with additional faculty from the Rossin College and Lehigh's College of Arts and Sciences). "Users submit a job, and depending on availability, the data is sent to systems across the world. Participating in the OSG allows Lehigh to be part of the national and international cyber infrastructure for scientific research."

Moving from 'condo' to 'complimentary' computing

Back in 2016, the university provided $150,000 in seed money to establish the existing HPC cluster, Sol. Since then, the hardware has been upgraded incrementally through contributions from individual researchers' grant awards and startup packages.

The setup, known as a "condo" computing model in the HPC community, was largely win-win: It enabled the university to build centralized research computing infrastructure while providing researchers (aka "condo investors") with system administration and support from Lehigh's Library and Technology Services.

Still, explains Webb, the arrangement had one clear drawback: "If you didn't pay, you couldn't play—there wasn't a way for researchers to garner no-cost computing at a level to generate the kind of preliminary data that makes a proposal more competitive for funding."

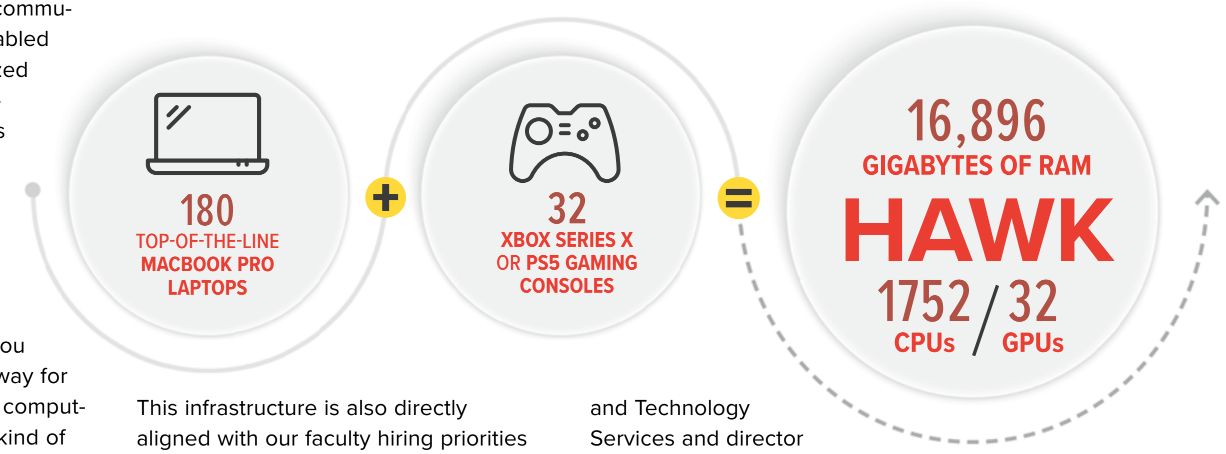
Hawk "increases the amount of computing available without requiring them to actually invest in the cluster," says Pacheco, clearing a barrier to entry and setting the stage for new stakeholders to "buy in" once proposals receive funding. It also provides new opportunities to train graduate students in HPC, he says, and teach undergraduates sought-after skills.

"Hawk will support ongoing collaborations while enabling new ones that require computation to get off the ground," Webb says, adding that data collected in connection with Hawk (e.g., papers published, proposals granted, graduate students trained) will help in going after larger instrumentation grants in the future.

Breaking boundaries with big data

Stronger research-computing infrastructure bolsters recent hiring efforts in the data science and computational space and aligns with priorities around team research that addresses engineering's grand challenges, says Stephen P. DeWeerth, dean of the Rossin College.

"It is critically important that Lehigh support state-of-the-art research-computing infrastructure to facilitate the success of our research and researchers," he says. "For example, all three of Lehigh's Interdisciplinary Research Institutes (IRIs) rely heavily on HPC to pursue hard problems in areas including intelligent systems, cyber-physical infrastructure, and the design and characterization of novel materials. This infrastructure is also directly aligned with our faculty hiring priorities and is essential to our recruitment of outstanding faculty members."



One of those researchers is Webb, who uses HPC for molecular simulations as part of a multidisciplinary research team investigating the human blood protein von Willebrand Factor—work that could lead to advances in drug delivery for treating cardiovascular disease.

Yet the potential for collaborations that harness the power of advanced computing isn't limited to science and engineering, notes Robert Flowers, Herbert J. and Ann L. Siegel Dean of Lehigh's College of Arts and Sciences.

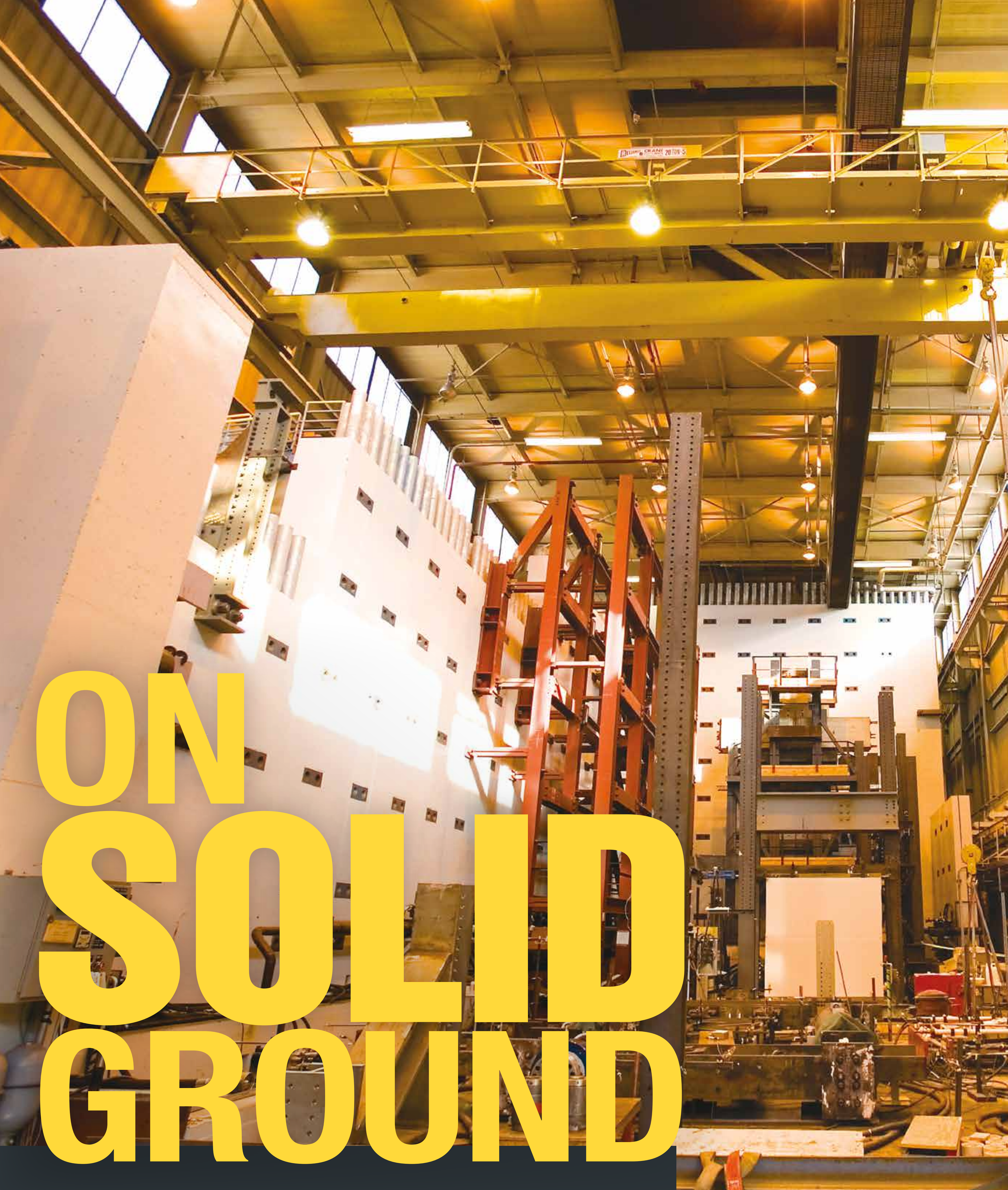
"There are many opportunities where data intersects with humanities and the social sciences," he says. "A great deal of the work by our colleagues in these areas now requires computation to solve the complex problems they are studying."

For instance, Flowers points to Haiyan Jia, an assistant professor of journalism and communications, who is working with computer science and engineering faculty members Brian Davison and Jeffrey Heflin. Their NSF-funded project is investigating new approaches to full-content dataset search that would serve both scientists and journalists in their pursuits.

Faculty members in both colleges are also designing classes and pedagogical approaches that combine data science and social justice topics.

Increasing participation in the HPC community—and using it to generate new knowledge—requires more than just the right hardware, says Greg Reihman, vice provost for Library and Technology Services and director of the Center for Innovation in Teaching and Learning.

"It's never just the computers," he says. "It's the networking underneath the surface, the HVAC system that keeps the data center cool, all the infrastructure involved. And, of course, it comes down to having skilled staff who keep it all running. With the launch of Hawk, we're celebrating the growth we've seen over the past few years in creating these shared resources—and we're looking ahead to what's next."



ON SOLID GROUND

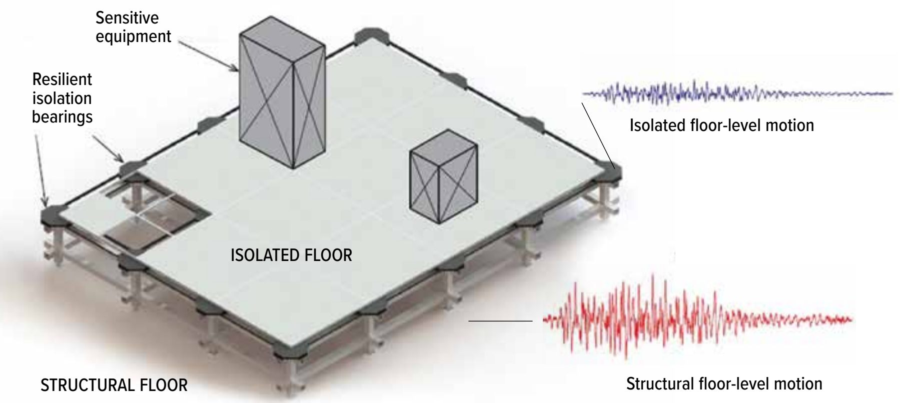
BY AMANDA ALLEKOTTE

Recently renewed by the NSF, Lehigh's Natural Hazards Engineering Research Infrastructure Experimental Facility provides unique simulation capabilities for studying resilience

EQUIPPING BUILDINGS in earthquake-prone areas with floor-isolation systems (FISs) could protect the people and property housed inside—and help ensure a quicker, less costly recovery.

The systems, which decouple the motion of the floor from the response of objects during an earthquake, would enhance the resilience of essential facilities, such as hospitals or power plants, by protecting sensitive, critical equipment, says P. Scott Harvey, an associate professor of civil engineering and environmental science at the University of Oklahoma. "By reducing or eliminating downtime in the wake of an earthquake, FISs are a promising retrofit strategy for protecting vital building contents."

Harvey's research on FISs has relied on data from shake-table tests, a widely used experimental tool for evaluating the seismic performance of structures. However, "these tests have been limited by payload and dimension capacities of our facilities" and cannot incorporate interactions between a building and a FIS system, he explains.



Tests conducted at Lehigh will help quantify the performance and limitations of FISs as a strategy to improve earthquake resilience.

To overcome those hurdles, Harvey and a graduate student spent five weeks during 2020 on a fellowship at Lehigh's Natural Hazards Engineering Research Infrastructure (NHERI) Experimental Facility (EF), taking advantage of its state-of-the-art real-time hybrid simulation capabilities.

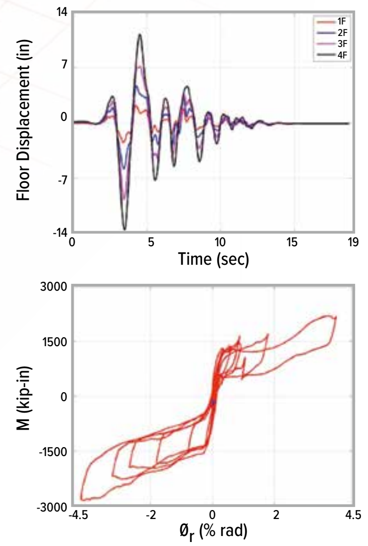
The NHERI Lehigh EF was created in 2016 with major support from the National Science Foundation as part of a national initiative aimed at improving the resiliency and sustainability of civil infrastructure to better withstand the effects of earthquakes and other natural hazards. It was preceded by Lehigh's Network for Earthquake Engineering Simulation (NEES) Real-Time Multi-Directional (RTMD) facility.

Since its inception, the NHERI Lehigh EF has operated as a world-class, open-access facility within the Lehigh's Advanced Technology for Large Structural Systems (ATLSS) Engineering Research Center, now under the umbrella of Lehigh's Institute for Cyber Physical Infrastructure and Energy (I-CPIE). Over the past five years, it has welcomed researchers from across the country addressing diverse structural engineering research topics associated with the challenge of community resilience.

In January 2021, the NSF awarded Lehigh a $5.3 million grant renewing the facility for another five years under the continued leadership of James Ricles and Richard Sause. (Ricles is Bruce G. Johnston Professor of Structural Engineering and director

> "The NHERI Lehigh EF provides researchers, both **internal** and **external** to Lehigh, with a world-class facility focused on mitigating the impacts of earthquake and wind hazards on large structural systems of the infrastructure."
>
> —Richard Sause

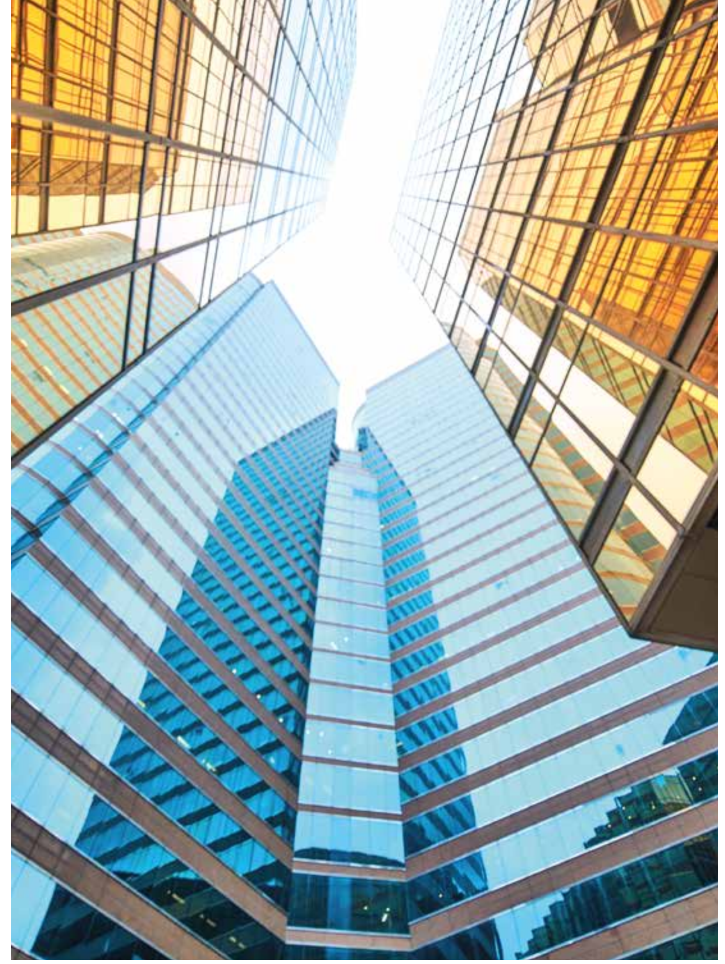
of Lehigh's RTMD Earthquake Simulation Facility; Sause is Joseph T. Stuart Professor of Structural Engineering and director of I-CPIE.) The funding ensures that researchers like Harvey will have access to the facility's unique experimental resources and data management for NSF-supported research and education awards.



"Leading in the development, implementation, and use of real-time hybrid simulation for large-scale laboratory testing, the facility offers researchers unique advanced testing algorithms that utilize the portfolio of resources," says Ricles. "The research performed here will increase our knowledge of the physical response characteristics, vulnerabilities, and factors that influence the resiliency of the civil infrastructure."

The facility also supports I-CPIE's commitment to fostering interdisciplinary research within and beyond Lehigh's campuses. "Large structural systems of the infrastructure are a key research thrust within I-CPIE," notes Sause. "The NHERI Lehigh EF provides researchers, both internal and external to Lehigh, with a world-class facility focused on mitigating the impacts of earthquake and wind hazards on these structural systems."

Over the years, Chad Kusko, operations manager for the NHERI Lehigh EF and director of operations for I-CPIE, has helped to organize workshops focused on bringing researchers to tour the facility and become more familiar with its capabilities. The most recent on-campus two-day workshop was held in September 2019 (in conjunction with the NHERI facility at UC San Diego and the NHERI SimCenter at UC Berkeley) and drew almost 40 participants, with the goal of generating new NSF proposals. The event also included presentations from researchers and a discussion led by researchers who have utilized the NHERI Lehigh facility to investigate grand-challenge natural hazards engineering research topics.



"It's clear that interest in NHERI and its facilities remains strong," says Kusko, and "the opportunities that utilizing NHERI facilities can provide researchers are unique."

Research teams can perform accurate, large-scale, multi-directional, real-time hybrid simulations (RTHS) that combine physical experiments with computer-based simulations (a form of cyber-physical systems research) for evaluating the performance of systems subjected to natural hazards. This might include studying the effects of soil-foundation structure interaction under wind and earthquake hazards, for example, or, in Harvey's case, investigating innovative floor-isolation systems.

Harvey and grad student Braulio Covarrubias Vargas conducted an extensive series of tests using Lehigh's RTHS capabilities to characterize and evaluate a FIS configured with a rolling pendulum isolation bearing and augmented rolling resistance. The cyber-physical tests measured both FIS-equipment and building-FIS interactions.

LEFT: WALTER MOONEY/U.S. GEOLOGICAL SURVEY; TOP: EASYTURN/ISTOCK

TOP: CHRISTA NEU; CENTER: COURTESY OF I-CPIE

Since 2016, the NHERI Lehigh EF has provided graduate students, such as those advised by Ricles (center), opportunities to gain experience in RTHS techniques.

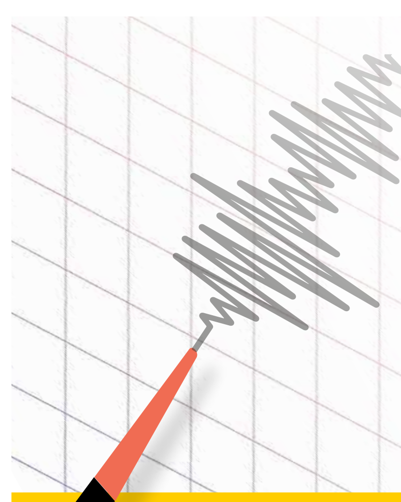
Knowledge gained will enable the development of **innovative materials** and **structural concepts** for **more resilient** infrastructure.

Harvey credits Ricles, Sause, Kusko, and other personnel for providing expertise in RTHS that eased the development of the test protocol and expedited the setup time, which allowed for a greater breadth of tests to be conducted.

Ultimately, Harvey says, this research, which builds on years of work on equipment isolation by his group at the University of Oklahoma, will help advance understanding of these devices' complicated nonlinear dynamics. The data collected at Lehigh will be used to calibrate and validate physics-based mathematical models of the rolling pendulum bearings. He plans to return this summer for the second phase of the project, which will include the development of an experimental testbed for multi-directional RTHS testing of FISs.

Ricles says that the large-scale real-time experiments performed at the NHERI Lehigh EF will lead to the acquisition of rich data sets and creation of high-fidelity computational models for the purpose of performing advanced numerical simulations. Additionally, the knowledge gained will enable the development of innovative materials and structural concepts.

The vision for the next five years is clear, Ricles says: "The NHERI Lehigh will continue to foster advances in community natural hazard resilience that will be implemented into engineering practice, as experimental data and related computational models are used to validate new, innovative structural concepts for design and retrofit."



RECENT NHERI LEHIGH EF PROJECTS

- **ADVANCING KNOWLEDGE ON THE PERFORMANCE OF SEISMIC COLLECTORS IN STEEL BUILDING STRUCTURES** (University of Arizona)
- **RESILIENCE-BASED SEISMIC DESIGN METHODOLOGY FOR TALL WOOD BUILDINGS** (Lehigh University, Colorado School of Mines, Washington State University, University of Nevada, Colorado State University, University of Washington)
- **SEMI-ACTIVE CONTROLLED CLADDING PANELS FOR MULTI-HAZARD RESILIENT BUILDINGS** (Lehigh University, Iowa State University)
- **QUANTIFYING SEISMIC RESILIENCE OF MULTI-FUNCTIONAL FLOOR ISOLATION SYSTEMS THROUGH CYBER-PHYSICAL TESTING** (University of Oklahoma)

REMEMBERING PETER BRYAN

A knowledgeable, dependable colleague. A man of patience, good humor, and grace. A mentor, big brother, and friend.

Those are just a few of the ways friends and colleagues describe Peter Y. Bryan, manager of computer and information technology at Lehigh's Advanced Technology for Large Structural Systems Engineering Research Center, who died in November 2020 at the age of 56.

"Peter was a tremendously caring, helpful, and thoughtful person who enabled all of us to be successful in our work," says ATLSS director Richard Sause. "Each of us can recall times when he helped us through a difficult problem or situation. He was always willing to help. We miss him deeply."

A civil engineering alum (Class of 1988), Bryan leveraged his knowledge of the discipline and his professionally developed experience in IT into a fruitful 32-year career at Lehigh. He was also deeply involved in supporting programs, including CHOICES and PreLUsion, that introduce the concepts of engineering to young people and generate excitement for the field.

He was clearly beloved by colleagues and students—both current and past—as evidenced by the outpouring of tributes to his kindness and generosity shared online.

"Peter was a fixture of our civil and environmental engineering family," says Shamim Pakzad, associate professor and interim CEE chair. "His can-do attitude combined with a genuine desire to say 'yes' to help everyone made him the person that we all loved and adored."

“WE TEACH ENGINEERING CLASSES WHERE THE EQUATIONS ARE A HUNDRED YEARS OLD, SO THERE’S ALWAYS A REAL CHALLENGE TO MAKE IT NEW FOR OUR STUDENTS. IN SOME WAYS, THE PANDEMIC PROVIDED THE OPPORTUNITY FOR US TO MAKE IT NEW FOR OURSELVES. WE WERE FORCED TO DO SOMETHING DIFFERENT—AND WE IMPROVED BECAUSE OF IT.”

—Professor James Gilchrist

Teaching in the time of coronavirus

As engineers, we are trained to embrace challenges and find satisfaction in solving problems. Over the past year, educators across the Rossin College have applied the same mindset to keep students engaged in the remote classroom, whether they were “Zooming in” from South Bethlehem apartments or watching recorded lectures from childhood bedrooms across the world.

When the pandemic hit, faculty members got camera-ready in a hurry, familiarizing themselves with video equipment and virtual backgrounds. There were new methods of collaboration to try (like Slack and Jamboard) and hands-on lab projects to adapt for at-home DIY. Some professors went back to basics, using what they had on hand (think: costumes and props from the kids’ dress-up bin); others extended a virtual hand, offering students oft-needed personal support and empathy. As the months went on, we espoused flexibility, managing online, hybrid, and in-person models of instruction as the spread of the virus dictated.

In short, Rossin College faculty members ensured that remote teaching was truly remote learning—and, in the process, learned lessons about educational delivery and pedagogy that may shape the Lehigh experience well beyond the pandemic.

As we close out another unusual but successful semester—and train our focus on returning to a more typical campus environment in the fall—we reflect on teaching in the time of coronavirus.

“Making the rapid transition to online instruction in March 2020 was challenging for all of us. However, we had the advantage of already knowing our students, and this established rapport made the changeover a bit easier. In August, we didn’t have that benefit. My Fall semester classes were considerably larger and, therefore, it was important to establish and maintain a connection with my students in the Land of Zoom. My strategy was simple: I always greeted the students by name at the start of class. This basic act is a no-brainer, but it does facilitate a connection. Some students who arrived early liked to have a conversation, even at 9 AM. I also asked the students to turn on their camera and microphone at the beginning and end of class to wave hello and good-bye. These small steps are my way of telling the students that they’re seen and heard.” *—Professor of Practice Lori Herz*

“Before the pandemic, I regularly found myself asking, ‘How do we make lectures optimally beneficial to the education of the students?’ Teaching live lectures over Zoom was, of course, a shift in reality. Nonetheless, despite the little black rectangles, despite staring into a tiny camera, I was amazed by how much things were the same: Make the class active and collaborative, and students will enthusiastically follow. Breakout rooms for small-group problem-solving were the most dynamic moments in the class. My TA joined me for those classes so we could both jump between rooms and answer student questions. It was intensive, and those sessions often went beyond the typical 50-minute lecture time and into the additionally scheduled 25 minutes. But I received zero complaints and a lot of encouragement to do those more often. I also went a bit whimsical with the final course project and had students design and perform stress analysis on a swing set. Lehigh students consistently impress me when I give such assignments and this term was certainly no exception.” *—Associate Professor Edmund Webb III*

“There’s the argument that if you record the lectures, no one will to go to your class. And that’s how I might have seen it earlier in my career. But in my recent experience during the pandemic, and in the graduate distance classes I’ve taught at Lehigh, the students are paying attention on Zoom. They can focus on absorbing and processing information during the lecture, rather than frantically scribbling down notes, because they know they can always go back to a recording if they miss something. I haven’t seen any decreased engagement in my classes. It may not be possible to do this in a typical classroom setting, but it was one bright spot of teaching ‘during covid.’ I’d like to provide students that opportunity to review material on their own time and see it a second or third time going forward.” *—Associate Professor Angela Brown*

“What has been my role as a capstone team advisor during a pandemic? To empathize, to guide, to remind teams that even big challenges don’t diminish need—and that ‘online’ can mean ‘new opportunities.’ For example, Team ENABLE has been working (since February 2020) to design two unique sets of prosthetic fingers for a member of the local community who suffered digit amputations on both hands. From day one, the team was inspired by their client’s resilience and can-do attitude. They were eager to put their engineering skills to use to provide an affordable solution that would enable their client to accomplish everyday tasks. Then came COVID-19 and the switch to online learning—and suddenly a ‘sure bet’ no longer felt the same. I assured them that progress comes in packages of all sizes, that resources are all around if you are open to seeing them, that innovation comes from pushing boundaries—including self-imposed ones. The students have taught me that despite adversity, when opportunity and resources (even unexpected ones) are combined with students having the will to succeed and the passion to make a difference, the possibilities are boundless.” *—Professor of Practice Susan Perry*

“We’ve done a lot of ‘flipping the classroom,’ meaning lectures are recorded and class time is spent working through problems, but I’ve also found value in flipping the advising model. When the pandemic took away summer internships, I saw the opportunity to engage undergraduates in an effort to enhance the chemical and biomolecular engineering department. Ten students signed up for this one-credit summer outreach project, which included designing a new, introductory-level chemical engineering course that’s open to all majors. Right now, I’m teaching Coffee and Cosmetics: Engineering of Consumer Products, which looks at principles of scale-up, mass balances, transport, and process design using two familiar product categories. The student input really created the activation energy to make this happen, and now we are brainstorming larger goals to develop a lab facility around this class. *—Professor James Gilchrist*

ALEKSANDRA MATAFONOVA/ISTOCK

As a 2021 recipient of the NSF CAREER award, Rangarajan joins a distinguished group of Lehigh faculty recognized nationally for early-career excellence. Read more in the next issue of *Resolve*.

A 'model' teacher and researcher

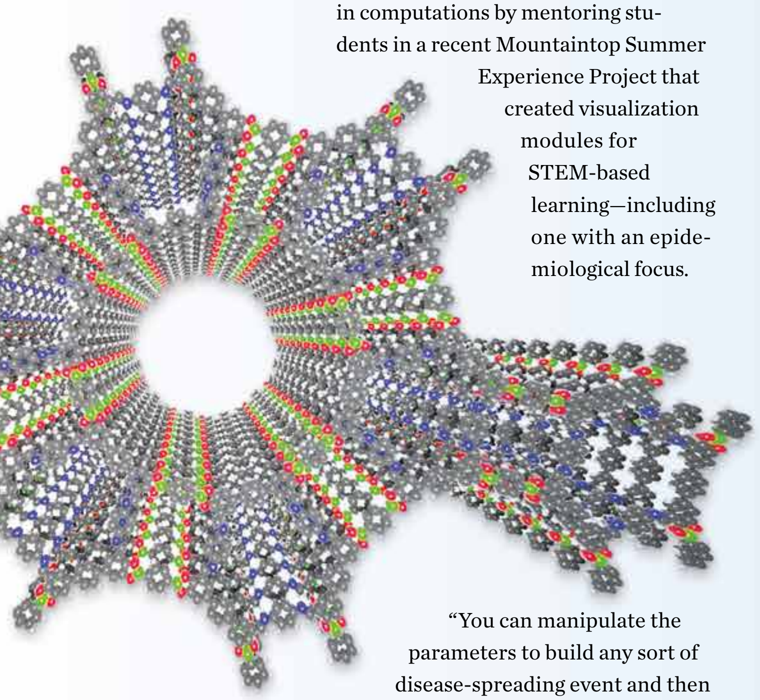
Chemical engineer takes a computational approach to investigate, explain complex processes

Chalk up 2020 as the year data visualizations truly went viral.

Across the internet and social media, simulations with bouncing balls helped us understand the spread of disease, and interactive charts and graphs gave us a better grasp of how masks, lockdowns, and social distancing might flatten the COVID-19 curve.

"People have been exposed to the world of mathematical modeling through this pandemic," says Srinivas Rangarajan, an assistant professor of chemical and biomolecular engineering (ChBE). "Models and their resulting projections have been the cornerstone of a lot of the recent decision-making in the United States in response to coronavirus."

Rangarajan shared his expertise in computations by mentoring students in a recent Mountaintop Summer Experience Project that created visualization modules for STEM-based learning—including one with an epidemiological focus.



A BALL MODEL OF TRIPOROUS COVALENT ORGANIC FRAMEWORK; ILLUSTRATION COURTESY OF CHRISTOPHER RZEPA

"You can manipulate the parameters to build any sort of disease-spreading event and then get a sense of the dynamics, or how the different populations—exposed, hospitalized, recovered, and so on—change over time," he says. "I see it as a chemical engineering problem or, at the very least, one that uses similar mathematical modeling concepts and engineering processes."

Rangarajan considers himself an "accidental" chemical engineer, having been set on the path following his high school exams in India. However, he quickly found that the discipline's combination of chemistry, physics, and math suited him. His decision to take a computational direction was, in part, driven by practicality ("you don't need a lab space or infrastructure, just a laptop") and solidified by experiences.

"My internship was about building mathematical models and chemical processes for making polymers," he recalls. Later on, he went to the Netherlands to work for Shell, developing models for a new chemical process for converting natural gas into fuels and lubricants. "These opportunities gave me insight into the value of computational sciences and just how useful modeling can be, not just in terms of understanding, but also for process optimization and maximizing profitability."

A desire to delve into academic research took him first to the University of Minnesota to work on modeling complex reaction networks in biomass and hydrocarbon conversion, a project that Dow partially supported. As a postdoc at the University of Wisconsin, one of his projects was with BP on removing sulfur from crude oil to produce ultra-low sulfur diesel. The experience trained his sights on heterogeneous catalysis, while introducing him to quantum chemistry.

"With quantum chemistry, you can computationally understand what's happening in a reaction system at the level of individual atoms and then use that information to design a new chemical process."

Answering increasingly complex research questions requires interdisciplinary collaboration, says Rangarajan, who points out that he always had a pair of advisors (one who specialized in mathematics; the other, chemistry or catalysis) throughout his advanced studies.

"Modern science and engineering isn't done in an individual setting. You can't solve today's problems by only doing computations or only experiments. You need to team up and use a combination of tools."

That mindset—combined with an appreciation for Lehigh's strengths in experimental catalysis, synthesis, materials science, and microscopy—brought him to the Rossin College in 2017, a decision that has resulted in collaborations with fellow ChBE faculty members Jonas Baltrusaitis, Mark Snyder, Jeetain Mittal, and Israel Wachs, among others.

On the topic of catalysis, Rangarajan is working with Baltrusaitis to find energy-efficient alternative routes to produce ethylene and propylene (used in plastics). The current process consumes more than three exajoules of energy and releases more than 200 metric tons of carbon dioxide globally every year.

"We are moving away from using conventional sources of carbon such as crude oil to newer sources such as biomass, shale gas, and even waste CO_2 to produce various products," he says, "so the question that interests me is how do we engineer new catalytic processes to make them more material efficient and have less CO_2 impact?"

Rangarajan was also awarded a $420,000 NSF grant with Snyder (a materials synthesist) and Mittal (an expert in molecular simulation) focused on an emerging class of porous materials called covalent organic frameworks (COFs). The team is developing a computational method to guide experimental efforts in synthesizing COFs, which have tiny (i.e., sub-nanometer scale) pores, from billions, or possibly trillions, of building-block combinations.

"Because we can make these materials with pores of multiple sizes and structures, they can find a wide variety of applications in areas like catalysis, energy storage, and drug delivery," Rangarajan explains.

The group's workflow, which integrates computational and experimental approaches, illustrates the power of tackling a problem from multiple angles. To be successful, he says, requires "a critical group of people who provide a complementary perspective to your own."

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CATALYZING INNOVATION

Lehigh's "interactive culture" supports interdisciplinary research collaborations that can benefit the world, says Rossin College ChemE professor, NAE member, and Bell Labs alum Elsa Reichmanis.

See page 8