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resolve

A FOCUS ON LEHIGH ENGINEERING • VOLUME 2, 2017

EMPOWERING THE SMART CITY

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LEHIGH UNIVERSITY | P.C. ROSSIN COLLEGE OF ENGINEERING AND APPLIED SCIENCE

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A FOCUS ON LEHIGH ENGINEERING

VOLUME 2, 2017

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Envisioning our shared future

Welcome to the Fall 2017 issue of* Resolve*—a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh University.

I have truly enjoyed my first year as dean of the Rossin College! I am continually inspired by the passion, ingenuity, and motivation of the members of our College and University community. We are working together to aggressively enhance the strategy and mission of the College. I wanted to take this opportunity to provide an update on our progress.

Last year, we initiated an Envisioning Process for the Rossin College. We used this faculty-led process to gather thoughtful feedback from across our community and to set targets for strategic growth and investment in our future. The process focused on innovating our learning environments and on enhancing our research culture, impact, and reputation.

One primary outcome of the Envisioning Process was the identification of a set of interdisciplinary research themes in which Lehigh has the potential to make a significant long-term societal impact. Three initial themes have emerged: Materials and Devices, Data and Computation, and Infrastructure and Energy. By building upon our current strengths and by strategically investing in our future, Lehigh intends to be among the leading research universities in the world in these focused areas. These themes and the associated proposed Interdisciplinary Research Institutes are the focus of our "Special Feature" that starts on the very next page of this magazine.

Throughout this issue of *Resolve*, you will notice many examples of ongoing research that align with these themes, along with other developments around campus that serve to bolster and support our strategy.

The main feature article is centered on our researchers' approach to "Smart Infrastructure for Connected Communities" (p. 16). It serves as a perfect example of a set of interrelated research challenges that sits squarely within our interdisciplinary framework. The demands and side effects of society's reliance upon energy, communications, structural, and transportation systems—magnified greatly in an urban setting—requires a broad approach that's focused not only engineering systems, but on engineering of systems to improve lives.

Other articles in this issue cover similarly connected topics in areas such as robotics and UAVs (p. 12), healthcare data mining (p. 6), solar cell production (p. 9), cancer detection through artificial intelligence (p. 7), and structural resilience (p. 8), to name a few.

Over the summer of 2017, we proudly launched a new Department of Bioengineering (p. 10) within our College. This formal designation as a department reflects the importance of the field, as well as its emergence at Lehigh over the past 15 years. The Department will undoubtedly serve as conduit between Rossin College and Lehigh's forthcoming college for integrated health.

The renovation of Building C—an expansive, they-don't-make-them-like-this-anymore industrial structure recently taken over by Lehigh—is coming down to the final stretch. When completed, the building will retain its 'Beth Steel'-era charm, but will be reborn, as the article says, as a cutting-edge center for 21st century innovation and education.

Last but certainly not least is an article about efforts underway across our College to enhance the diversity of our community. While there's a lot of work to be done in this area, programs such as the Greer Scholars, ADVANCE, and CHOICES are great examples of Lehigh stepping up and doing its part to open the doors of engineering to any talented mind willing to take on the challenge.

Many of the stories above are provided in greater detail online; Please check the magazine's Web site, lehigh.edu/resolve, to learn more about these and other topics.

"These themes are areas in which Lehigh should be among the leading research universities in the world."

Thank you as always for your interest in Lehigh engineering and the Rossin College, please drop me a line with your thoughts and comments.

Stephen P. DeWeerth, *Professor and Dean*
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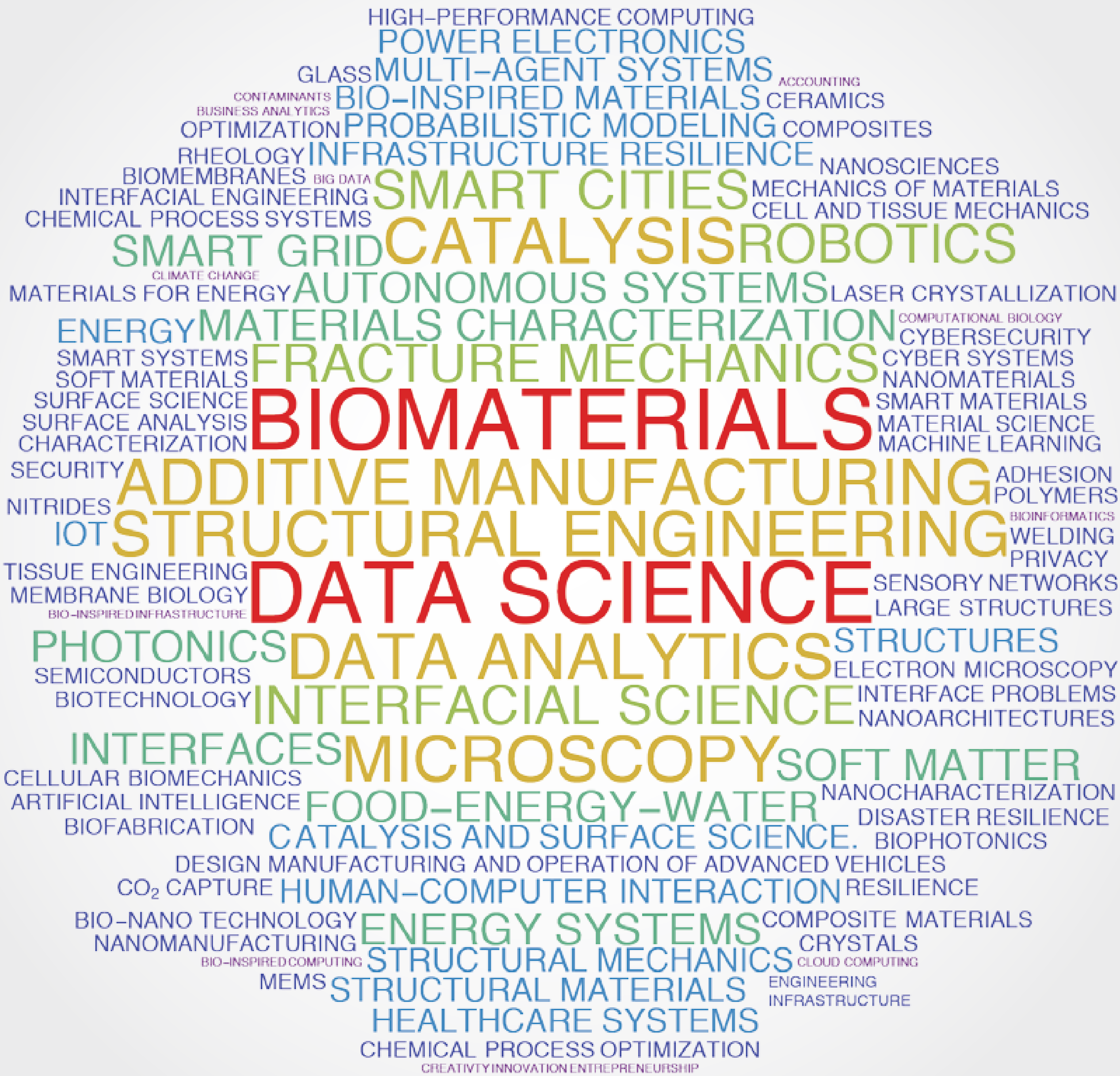
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POWER ELECTRONICS
GLASS MULTI-AGENT SYSTEMS ACCOUNTING
CONTAMINANTS BIO-INSPIRED MATERIALS CERAMICS
BUSINESS ANALYTICS
OPTIMIZATION PROBABILISTIC MODELING COMPOSITES
RHEOLOGY INFRASTRUCTURE RESILIENCE NANOSCIENCES
BIOMEMBRANES BIG DATA
INTERFACIAL ENGINEERING SMART CITIES MECHANICS OF MATERIALS
CHEMICAL PROCESS SYSTEMS CELL AND TISSUE MECHANICS
SMART GRID CATALYSIS ROBOTICS
CLIMATE CHANGE
MATERIALS FOR ENERGY AUTONOMOUS SYSTEMS LASER CRYSTALLIZATION
ENERGY MATERIALS CHARACTERIZATION COMPUTATIONAL BIOLOGY
CYBERSECURITY
SMART SYSTEMS FRACTURE MECHANICS CYBER SYSTEMS
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SURFACE ANALYSIS MATERIAL SCIENCE
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HEALTHCARE SYSTEMS
CHEMICAL PROCESS OPTIMIZATION
CREATIVTY INNOVATION ENTREPRENEURSHIP

FOCUSING ON QUESTIONS THAT MATTER

New campus institutes will amplify and promote broad-based interdisciplinary research

Over the past year, the Rossin College has undertaken an Envisioning Process to advance the University's commitment to excellence and leadership in research and education. As a result of this process, the College is spearheading a campuswide effort to create dedicated Interdisciplinary Research Institutes focused on long-term societal needs in areas where Lehigh is poised to lead on the national and international stage. Building on Lehigh's existing strengths, these institutes will serve as a focal point for future investments in the recruitment of faculty and students and in the expansion of world-class research programs and facilities.

"We are focusing on research themes that have the potential to broadly impact our scholarly communities and society as a whole," says Stephen DeWeerth, professor and dean. "Toward that end, these institutes will engage a community of scholars who will address interdisciplinary research challenges through the incubation of ideas, the facilitation of interdisciplinary teaming, and the realization of these ideas and teams in large-scale, extramurally funded projects. The institutes will also assure that Lehigh is an international beacon of excellence across these themes, promoting our thought leadership and linking us to a robust set of external stakeholders."

According to John Coulter, senior associate dean for research, these institutes will be centered in the Rossin College but will reach into all relevant corners of campus. "We believe these institutes will enable us to solidify and further develop our strengths in key areas, and then project that strength more deliberately to the outside world," he says. "This will enable greater success for faculty-led research endeavors, and students at all levels will benefit from greater access to expertise, facilities, and partnerships across key facets of industry and society." Faculty councils have formed to define and propose the creation of institutes across three initial themes:

MATERIALS AND DEVICES

Synthesis, fabrication, processing, and characterization of engineered materials, devices and systems are cross-cutting areas of research in which Lehigh has significant scholarly activity. Areas of interest include photonics and electronics, metals, ceramics, biomaterials, polymers, and composites. Soft matter focal areas include soft biomaterials, gels, elastomers and colloidal assemblies. These materials are incorporated in devices ranging in size from the nanometer and micrometer scales and beyond, for application to many industries such as aerospace, biomedicine, microelectronics, renewable energy, and photonics.

DATA AND COMPUTATION

This theme is devoted to the study of problems that involve massive amounts of data and/or large-scale computations, and developing the science that enables the extraction of useful and actionable information across disciplines and research fields. Volumes of undifferentiated data are readily available from web pages, multimode feeds such as sound and video capture, satellite imagery ranging from high-altitude pictures to weather conditions, social media such as tweets and many others, medical data ranging from patient medical history to imagery of patient's organs, as well as outputs of computational simulations. Such effort by its nature requires interdisciplinary contributions from experts in many fields of science and engineering.

INFRASTRUCTURE AND ENERGY

These are the physical systems and engineered processes that underpin all aspects of modern society and its economy. Interdependent and increasingly adaptive, these systems are dedicated to such modern needs as communication and internet connectivity as well as the provision of electricity, food, fuel and water. Research in this field must also incorporate issues related to transportation networks, shipping and logistics facilities, residential and commercial structures, healthcare resources, materials, chemical, pharmaceutical and manufacturing facilities, as well as systems related to energy production and the capture and treatment of solid waste and wastewater.

A revolutionary overhaul

A piece of Bethlehem's industrial history transforms into a foundry of modern technology

At the very top of South Mountain, a renaissance of sorts is taking place. The unpretentiously named Building C, part of a 1960s complex that was Bethlehem Steel's outpost for research before it became Lehigh's Mountaintop Campus in the 1980s, is being reborn as a cutting-edge center for 21st century innovation and education.

The colossal, midcentury structure had been neglected since Bethlehem Steel folded. Lehigh acquired it in 2013 when Daniel Lopresti, who directs Lehigh's Data X initiative and is professor and chair of computer science and engineering, was one of the first to tour the dilapidated hulk.

"There were about half a dozen of us, faculty and administrators," recalls Lopresti. "The building was in serious disrepair—there were leaks in the roof and animals had gotten in. We started to scratch our heads and wonder how we could use it."

Inspired by floor spaces the size of playing fields, three enormous bays and soaring 60-foot ceilings, Lopresti's imagination kicked into high gear. "I remember thinking that it looked like a Google or Facebook complex, with bones that any urban tech startup would envy—and this was when the building was still abandoned," he says. "We could foresee a hackathon taking place, or research into coordinated swarms of robots, for example. The entire team of faculty and staff involved in the renovation project has been struck by the nature and spirit of the space—it is utterly perfect for thinking big."

Building C is currently in the process of a revolutionary overhaul, one that Lopresti calls a respectful repurposing. The project is preserving the industrial history and feel of the structure while creating a contemporary 'makerspace' for Lehigh researchers and students. When complete, the facility will act as a hub of research and education for interdisciplinary Lehigh teams and projects that leverage data science and analytics.

"It is utterly perfect for thinking big." —Daniel Lopresti

COURTESY EYP ARCHITECTURE & ENGINEERING

Lehigh, working with EYP Architecture & Engineering, the firm that designed the award-winning Urban Outfitter headquarters in the Philadelphia Navy Yard, has envisioned a facility that will capture the best features of leading tech firms, bringing a sense of SoMa to South Mountain. The design also infuses the interior spaces with the state-of-the-art tools and informal meeting spots that help give rise to creativity and collaboration, keys to survival and success in the modern technology environment.

The building will feature openness and broad sight lines to maintain the expansive feel of the original spaces. Large, glass-walled rooms dubbed "mixing boxes" will line one end of the interior, separating the work spaces from the office and administrative areas in the crescent-shaped approach that links the spoke-like wings of the building. The mixing boxes can be used for meetings, seminars or informal gatherings, and overlook the vast bays. Classrooms will be fitted for active learning, with the idea that students will cover course material prior to scheduled classes so that class time can be devoted to hands-on, experiential projects.

Lehigh has also invested in a major upgrade of the fiber optic network connecting Mountaintop with the lower campus. The building will have a telepresence room, the next generation in videoconferencing.

"Telepresence feels like about 98 percent of being in the same room with the other person," says Lopresti. "The almost-live feel of the telepresence technology, which requires a similar node on the other end, will, for starters, connect Building C with lower campus and to Lehigh's NASDAQ Entrepreneurial Center in San Francisco."

Building C will also be fitted with a 3D printing lab, a digital media lab, and traditional wood and metal shops for fabrication. Also envisioned are smart building features and a lab for 'Internet of Things' research that would enhance the efficiency of the structure and allow it to serve as a center for smart cities experimentation and design.

"This is a huge project," Lopresti says. "It is going to be a spectacular facility, and will enable a tremendous step change in Lehigh's interdisciplinary profile in research and education."

Boosting confidence in research outcomes

Probabilistic Modeling Group shines a light on emerging field

Paolo Bocchini believes that there's a hidden gem in Lehigh's academic portfolio, and with colleagues from across campus he's working to shine a light on this emerging research field.

Probabilistic modeling allows scientists and researchers to incorporate random variables and uncertain functions into their models of events or other phenomena. Whether designing an insurance portfolio, determining the life cycle of a transportation system, or calculating the likelihood of a pandemic, such models allow researchers to take into account the many uncertainties that influence the outcome of a given situation.

Bocchini, the Frank Hook Assistant Professor of Structural Engineering, says that a shift is happening in this field; it's not unlike the one that happened 30 years ago in computational modeling—and Lehigh is positioned to help lead the way.

"If you look back just a few decades, there were scientists and engineers using computers to model phenomena in various fields, but these efforts were centralized, and involved only a limited number of specialists," he says. "Nowadays, it is difficult or impossible to find a professional engineer, scientist, or researcher who does not engage in computational analysis, to some extent. It permeates everything."

At Lehigh, Bocchini began to see colleagues from different departments discussing various aspects of, or perspectives upon, the use of probabilistic modeling; he very quickly found more and more research around campus that relied on the application of the same principles.

Bocchini sent out a few exploratory e-mails to gauge interest in collaboration from these colleagues. Shortly thereafter, Lehigh's Probabilistic Modeling Group convened for the first time, starting with seven faculty members from six departments. Their initial goal was to coordinate teaching activities to provide students with the most effective means of learning the broad concepts of probabilistic modeling and to explore the intersection points among their areas of research.

Although their work aimed at wildly different application areas, their methodologies were quite similar, and Bocchini saw potential to expand the group and its impact at Lehigh and beyond.

Shortly thereafter, Bocchini and Javier Buceta, associate professor of bioengineering, co-wrote a proposal for a Collaborative Research Opportunity (CORE) Grant from Lehigh, which allowed them to coordinate research and educational activities in the area of probabilistic modeling.

Paolo says that there are probabilistic-modeling-centric projects underway across campus that are spawning partnership among faculty from mathematics, materials science, business, and physics, just to name a few.

"I was involved in drafting a proposal for funding from the National Institutes of Health," Bocchini says. "For me, a structural engineer, it was very surprising to think about submitting proposals to NIH. But researchers need to have a fundamental curiosity, and being able to apply my skill set and knowledge in completely different fields is very rewarding."

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A golden year for Lehigh microscopists

RESEARCH RECOGNITION

A talented team of Lehigh research students led by Chris Kiely, Harold B. Chambers Senior Professor in materials science and engineering, has had an amazing run recently—three of its research papers have been accepted and published in less than a year in separate monthly issues of *Science*, the world's premier science journal.

Specifically, the research centers on the use of gold to act as a catalyst for a variety of chemical reactions.

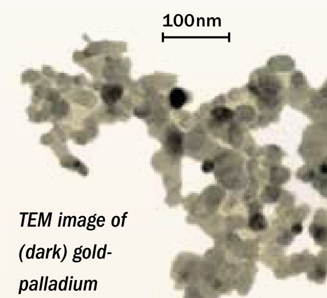
"Collectively," says Kiely, "these projects demonstrate that, when engineered into structurally different forms, gold can catalyse three very different, yet massively important, industrial reactions."

In March, Kiely's team helped unlock the secret of how highly dispersed gold atoms on a carbon support can catalyze a new, environmentally-friendly method of producing the vinyl chloride monomer used to manufacture polyvinyl chloride, or PVC.

The July issue of *Science* reported that another type of microstructure—comprising raft-like gold nanoparticles on a special type of molybdenum-carbide (α-MoC) substrate—had achieved a high level of catalytic activity at low temperatures for producing the pure streams of hydrogen necessary to power fuel cells.

In September, the team's hattrick was an article discussing their work on developing a promising new approach of using gold-palladium nanoparticles to directly oxidize methane to methanol, a widely used feedstock chemical that also has considerable potential as an alternative fuel source. The article is also the 10th Kiely has published to date in *Science*; he has also published four in *Nature*. The two publications are considered the world's leading science journals.

"These successes are built on having a fantastic cohort of Ph.D. students and developing long-term successful international collaborations over the years," says Kiely. "Through partnership with researchers at the Cardiff Catalysis Institute in Wales, Oak Ridge National Laboratories, as well as Peking University and the University of the Chinese Academy of Sciences in Beijing, we are using catalytic nanotechnology to contribute to solutions in energy, industrial chemicals production, and reducing environmental impact."



TEM image of (dark) gold-palladium nanoparticles on a titania support.

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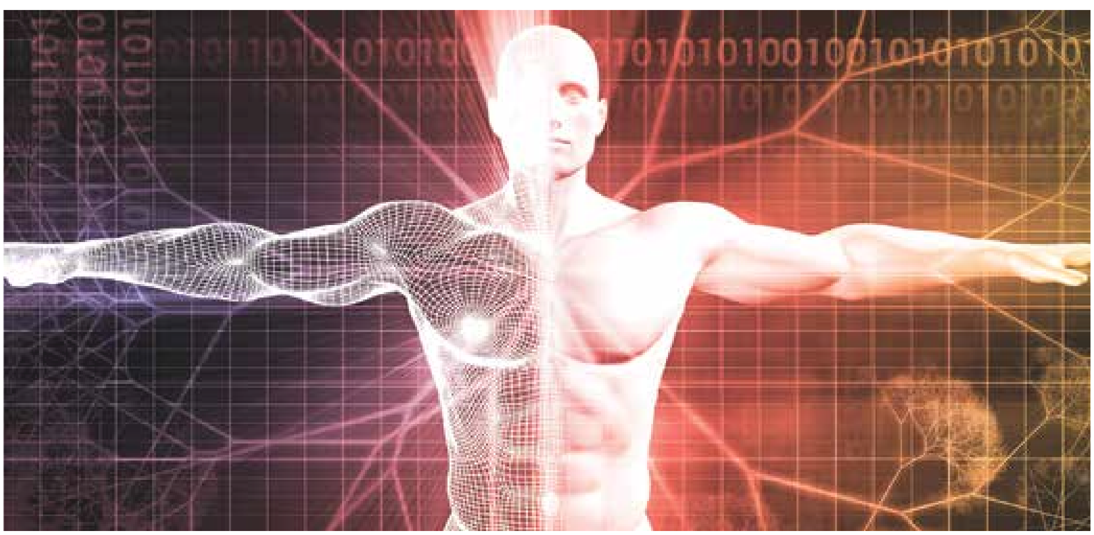
Improving disease prediction with Big Data analytics

Data mining to improve healthcare outcomes

Big Data holds great promise to change healthcare for the better. But its potential will not be reached until healthcare providers improve the efficiency with which data is shared and the accuracy with which it is interpreted.

Mooi Choo Chuah, professor of computer science and engineering, conducts research in next-generation wireless network architecture design, network and smart grid security, and mobile and cloud computing, and has recently begun to investigate healthcare data mining.



Mooi Choo Chuah (right) and her students are exploring the use of deep learning techniques in the field of healthcare data mining.

Her group's recent research offered two new insights on the topic, says Chuah. The first, an approach she developed with her graduate student, Qinghan Xue, uses a large dataset to demonstrate an improved disease prediction model that combines data cleaning and careful feature selection with effective machine learning techniques.

Chuah utilized a dataset made public by Prize4Life, which helped develop the Pooled Resource Open-Access ALS Clinical Trials (PRO-ACT) database, the largest database of clinical data from Amyotrophic Lateral Sclerosis (ALS) patients ever created. ALS is a progressive degenerative nerve disease, also known as Lou Gehrig's Disease.

In 2012, Prize4Life held a crowd-sourced competition to develop a method that accurately predicts ALS disease outcomes based on PRO-ACT's dataset. Teams competing in the Prize4Life contest sought to predict in which ALS patients the disease would progress slowly, at an average pace and rapidly. Prize4Life also asked researchers to predict how long ALS patients would survive from the date of diagnosis.

Like the teams in the Prize4Life competition, Chuah used the PRO-ACT database (which contains more than 10,700 records with 6,318 features) to predict which patients would fall into the three clusters of progression: slow, average or fast.

The challenge, says Chuah, was that the dataset was "very noisy."

"For example, some data were missing," says Chuah. "Some data were non-numeric—and, as you know, computers like numeric values."

Chuah's model cleaned up the data and improved the accuracy rate in predicting the rate of patients' ALS progression. Her method outperformed the winning team's—at 58.3 percent accuracy compared to 40.5 percent—and with fewer required features and higher quality data.

"We were able to predict where a patient would fall on the disease progression spectrum faster and with more accuracy," says Chuah. "This has implications for improved health outcomes and also for cost-saving—as a physician might see a patient with a faster-progressing disease more frequently, but less frequently for slow-progressing patients."

The paper's second contribution presents a solution to one of the major challenges of healthcare: the fact that no single hospital or health care system has enough of its own data for useful predictive disease analysis.

"Hospitals and other health care systems collect troves of data," says Chuah. "However, each has a limited number of patients experiencing a particular disease—such as ALS or diabetes, for example. We have designed an incentive method to encourage hospitals to share data so that better prediction models can be created."

The algorithm that Chuah and her team developed is designed to provide a "reward function" for each health care provider, identifying the cost per patient to participate in a crowd-sourced database. An individual hospital could use the incentive model to evaluate whether to participate. The model provides a "reward" for offering truthful, high-quality data.

Chuah believes that both elements of her latest research could improve the accuracy and usefulness of predictive disease models and, most importantly, patient health outcomes as well.

"In my work," she says, "I'm always looking to solve problems that will have some kind of positive social impact."

A revolution in polynomial optimization

According to Jie Liu, a Ph.D. candidate in industrial engineering, electric power should flow through the grid in a way that utilizes as efficiently as possible the resources that are used to produce it.

Liu and his adviser, Martin Takáč, assistant professor of industrial and systems engineering, working with Jakub Mareček of IBM Research, have made considerable progress in solving optimal power flow problems in the past two years.

The physics of alternating-current electricity makes these decisions difficult to make, says the group. But they correspond to polynomial optimization problems (POPs), which are a hot topic in the field of mathematical optimization.

Until recently, researchers could apply the so-called Newton method to POPs to obtain a solution quickly. Or, as suggested by Mareček and his colleagues, they could solve a sequence of surrogate problems to obtain the best possible solution.

The second approach often took too long, though, causing Liu, Mareček, and Takáč to seek conditions under which one could switch from the surrogate problems to the Newton method without obtaining solutions that would be wrong. Using recent developments in numerical algebraic geometry, the group has developed such conditions and designed methods to test them efficiently. One can therefore solve the surrogate problems quickly and, when it is safe, switch to the Newton method.

For his contributions, Liu recently received IBM's Ph.D. Fellowship Award, one of the industry's most competitive sources of funding for Ph.D. students.

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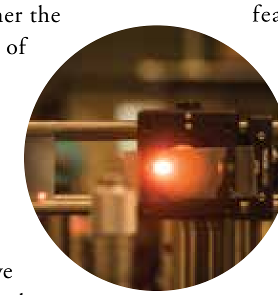
New tools in the fight against breast cancer

Nearly one in four women who have breast cancer and opt for a breast-saving lumpectomy will need a second surgery, increasing the cost of medical treatment and the risk of complications.

Surgeons freeze and examine surgically removed tissue to determine whether any cancer cells remain in the margin of tissue surrounding the excised tumor. But the accuracy of this approach is limited, and results are not available for days.

What if surgeons had a more accurate way to find out—in real time in the operating room—whether the tumor margins were free of cancer cells?



Chao Zhou, assistant professor of electrical engineering, and Sharon Xiaolei Huang, associate professor of computer science and engineering, have joined forces to develop a technique that can detect, in real time, the difference between cancerous and benign cells.

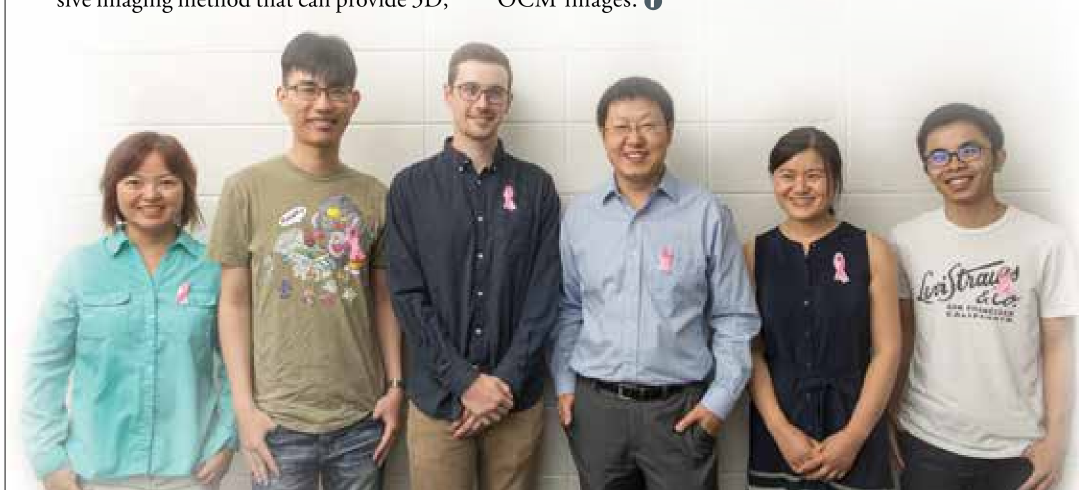
In a recent article published in *Medical Image Analysis*, the team reported that their technique correctly identified benign versus cancerous cells more than 90 percent of the time. The team includes researchers from MIT, Harvard Medical School, and Zhengzhou University.

Zhou, whose work focuses on improving biomedical imaging techniques, is a pioneer in the use of optical coherence microscopy (OCM), a noninvasive imaging method that can provide 3D, high-resolution images of biological tissue at the cellular level. Huang, an expert in training computers to recognize visual images, identifies the best way to analyze OCM images to differentiate between benign and cancerous tissue.

"The process takes a large number of images, and labels the types of tissue in the sample," says Huang. "For every pixel in an image, we know whether it is fat, carcinoma or another cell type. In addition, we extract thousands of different features that can be present in the image, such as texture, color or local contrast, and we use a machine learning algorithm to select which features are the most discriminating."

After examining multiple types of texture features, Huang and Zhou determined that Local Binary Pattern (LBP) features—visual descriptors that compare the intensity of a center pixel with those of its neighbors—worked best for classifying tissues imaged by OCM.

Experiments showed that by integrating a selected set of these features at multiple scales, the classification accuracy increased from 81.7 percent to 93.8 percent, along with high sensitivity—100 percent—and specificity—85.2 percent—for cancer detection using the OCM images.



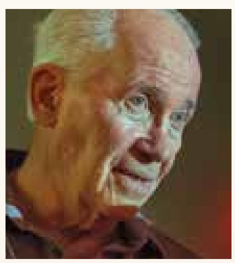
Professors Xiaolei Huang and Chao Zhou and their students are developing a technique that can detect cancer cells in real time.

Pioneer in fracture mechanics honored

RESEARCH RECOGNITION

Richard Hertzberg '65 Ph.D. retired two decades ago as the New Jersey Zinc Distinguished Professor in Lehigh's department of materials science and engineering. An expert in fracture mechanics, he spent his career studying the cracks that form and spread in airplanes, bridges, ships and other structures.

This spring, Hertzberg received the 2017 Paris Gold Medal from the International Congress on Fracture (ICF) for his contributions to the field of fatigue fracture. The award, given every four years, is named for the late Paul C. Paris, who was Hertzberg's Ph.D. dissertation adviser at Lehigh. Paris developed the Paris Law—a model of fatigue crack growth now used worldwide.



Richard P. Vinci, professor of materials science and engineering, says Hertzberg's work with fatigue—the structural failure brought on by repeated cycles of stress—underlies many of the safety standards adopted by the aircraft and automobile industries.

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"Dick worked with Paul Paris and others in the 1960s and 1970s to establish the theoretical and mathematical foundation for fracture mechanics," says Vinci. "He contributed to the rapid adoption of this approach in the aircraft industry."

Hertzberg also gained renown for his textbook, *Deformation and Fracture Mechanics of Engineering Materials*, first published in 1976 and now in its fifth edition, which has been translated into several languages.

Hertzberg, who earned his Ph.D. from Lehigh in 1965, has received Lehigh's Libsch Award for Outstanding Research, the College of Engineering Teaching Excellence Award and the Hillman Faculty Award for advancing the interests of the university. The department of materials science and engineering named him its distinguished alumnus in 2015.

Since retiring, he has lectured to a variety of lay audiences, from adult education classes to elementary and high school students.

Why did the Liberty Bell crack? Hertzberg will ask a class of teenagers or ten-year-olds. Why did the *Titanic* sink so quickly after its fatal brush with an iceberg? It is possible to determine how a crack formed and how it propagated and caused an entire structure to fail," he says. "The details on a fracture surface are like the fingerprints of a murder suspect on a glass of water."

Improving structural response to blast

When analyzing a structural element's ability to withstand the effects of a blast load, many engineers use a method called "single degree of freedom," or SDOF.

This simplifies the element down to its most basic form—a single mass, spring, and damper. These analyses typically take little time to run and are capable of reasonably modeling realistic behavior in many cases.

The method then posits that a fast-moving blast load—like the kind that affected structures in the vicinity of the Murrah Federal Building in Oklahoma City following the terrorist attack of 1995—will bend the element into the same shape as a static load.

"That assumption isn't bad for a wide range of blast loads," says Spencer Quiel, P.C. Rossin Assistant Professor of Structural Engineering, "but as the element gets closer to the blast, that bend tends to become more irregular."

Quiel says that as much as 75 percent of blast analysis in professional practice is conducted using the SDOF method, but he suggests the industry needs to recognize its limitations. If heeded, models would be developed to better capture irregular bending. Doing so, he says, would ultimately pave the way for safer and more economical structural design.

To achieve this, he has collaborated closely for the last three years with former colleagues at Hinman Consulting Engineers, the San Francisco-based structural engineering firm and global leader in "protective design" where Quiel worked before joining the Lehigh faculty.

"Working with companies, even in an advisory function, helps to keep researchers grounded," Quiel says.

That's ultimately why Quiel went to work at Hinman after completing his Ph.D. at Princeton studying fire resistance and the mitigation of resulting damage. When he arrived at Hinman, he and his colleagues began to pursue research and development possibilities that brought his knowledge to bear upon the area of blast mitigation.

"After grad school, I really wanted to branch out and learn some new things, and structural protection of government facilities, which Hinman does, always appealed to me from a service perspective," Quiel says. "Nothing is ever blast-proof or fire-proof, but we have levels of resistance in every type of structure. To engineer structures for the military, government employees, and private citizens that are as safe as they can be given for the resources we have, that's one of the central reasons I do what I do."

Finding better ways to incorporate irregularities into blast analysis will do just that, he says, even if the end result means companies need to utilize a more complex model when appropriate.

Quiel sees the future of research in this space as a collaboration among industry, government, and academia.

"As a researcher, industry engagement really makes you back up and see the bigger picture," Quiel says. "Where is this going? Who's going to use it? How will it impact the field? Is it influencing the field favorably or unfavorably? Does this fit within practice convention? Does it create a new paradigm or turn the industry on its head? Asking these questions during our research projects ensures that our work helps the industry move forward."

A tunnel to lower cost solar cells

Lowering the cost of solar cell production, thus making solar energy more affordable to individuals and businesses, could be a game-changer for the energy sector.

That is one of the reasons behind the U.S. Department of Energy's 2011 launch of the SunShot Initiative, a national effort to drive down the cost of solar electricity and to support the adoption of solar power.

An important area of focus for this effort is photovoltaic (PV) research and development. Solar cells contain a photovoltaic material—a substance that can transform sunlight into electricity. Traditional methods of making PV material require many steps and large amounts of energy, driving up the cost.

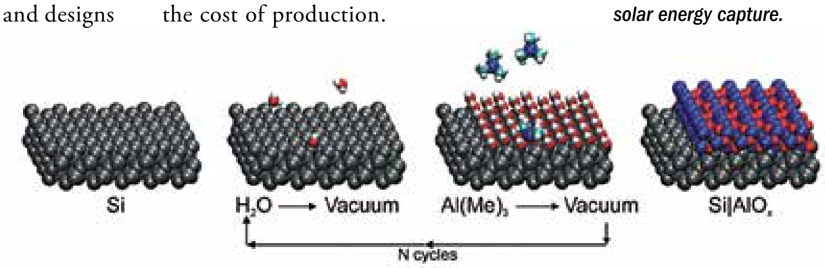
One way to lower the cost of solar cells, says Nicholas Strandwitz, assistant professor of materials science and engineering, is to reduce the amount of energy it takes to process silicon into a solar cell.

Strandwitz was recently awarded a grant through the SunShot Initiative's Photovoltaics Research and Development 2 funding program, which seeks to transform PV module design, explore high-risk emerging technology research, and develop devices and designs that facilitate rapid solar installation. Projects funded by this program will investigate new solar technology innovations that have the potential to make solar power affordable.

Strandwitz will explore a promising technique to manufacture solar cells using atomic layer-deposited (ALD) tunnel barriers, which are so thin that electrons can literally "tunnel" through them. He and his team will quantify the electronic behavior of silicon cells made with a combination of ALD tunnel barriers and metal oxide materials that selectively transport electrons with specific energies.

The creation of thin film layers and interfaces with the right electronic properties, says Strandwitz, can result in high-efficiency photovoltaics, while decreasing the cost of production.

Strandwitz's lab utilizes atomic layer deposition to develop semicodunctors with novel properties and applications, such as solar energy capture.



"Controlling interfaces and directing electron flow is essential for creating efficient solar cells," he says.

Toward sustainable struvite production

Struvite may not be a household word, but it is all too familiar to the operators of wastewater treatment plants.

When it crystallizes on equipment surfaces in treatment plants, says Jonas Baltrusaitis, struvite can clog pipes, requiring them to be chemically cleaned or replaced and, in some cases, forcing a plant to be shut down.

But there is a brighter side to the picture, says Baltrusaitis, an assistant professor of chemical and biomolecular engineering.

Struvite contains three nutrients vital to plant growth—nitrogen, phosphorus and magnesium. Treatment plant operators can recover these nutrients early in the wastewater treatment process and convert them to fertilizer. This must be done before the nutrients harm pipes and equipment and before they are discharged into the environment, where they pollute streams, rivers and lakes.

Baltrusaitis and his group have used advanced microscopy and spectroscopy techniques to study the formation of struvite crystals at the molecular level. Their work promises to lead to a cheaper, less energy-intensive conversion method and eventually to greater sustainability in wastewater treatment and in agriculture.

Most wastewater treatment plants, says Baltrusaitis, use insoluble iron or aluminum salts to recover phosphorus (phosphates) from sludge and then dispose of the nutrients in landfills. Water soluble magnesium salts such as magnesium chloride are used to form struvite, and thus enable recovery of nutrients.

"The traditional way of making struvite is not very sustainable," says Baltrusaitis. "Soluble magnesium salts are typically made from seawater or brine. Seawater has to be evaporated in order to recover struvite, and this requires a lot of energy."

Baltrusaitis and his group are proposing to form struvite by using naturally occurring and abundant magnesium oxide, dolomite or magnesium carbonate instead of the traditional method.

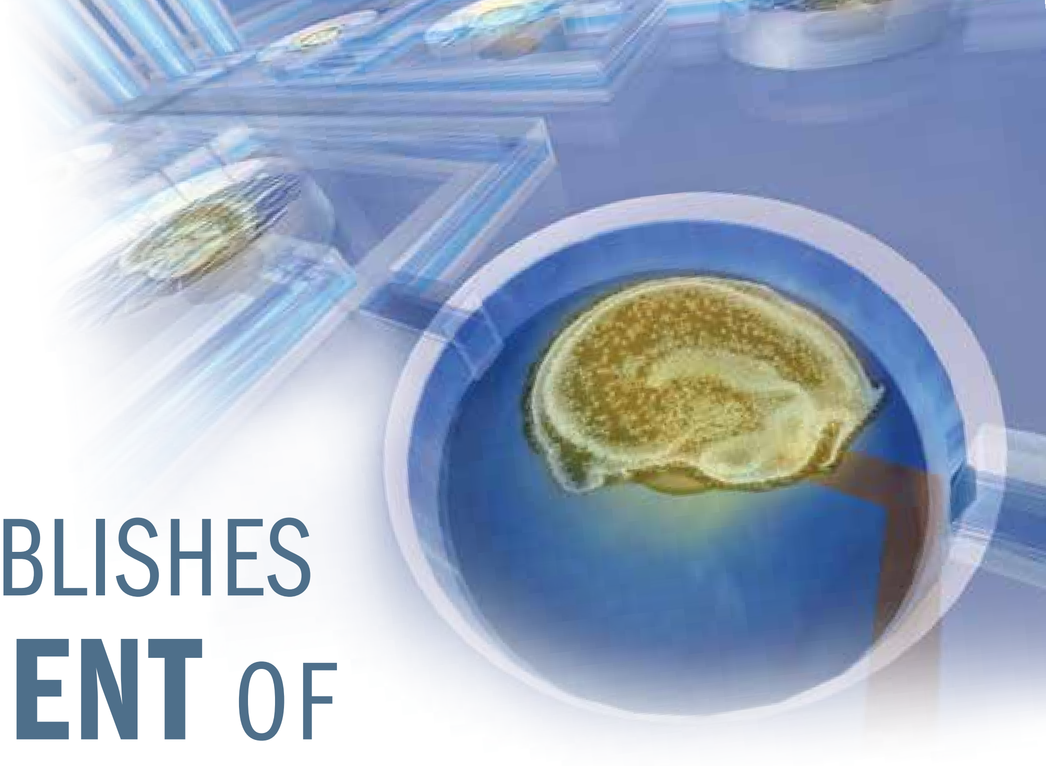
The work by his group, says Baltrusaitis, will lead not only to greater sustainability in the recovery of nutrients from wastewater, but potentially to greener agricultural practices as well.

"Waste from wastewater treatment plants is going to grow proportionally as population grows," he says. "The current technology, taking $MgCl_2$ from seawater, is less sustainable and is going to require more and more energy to recover nitrogen and phosphorus from animal waste and other waste.

"We believe we have devised a low-energy, low-environmental-impact technology that can potentially break this spiral."

The use of magnesium oxide and carbonate to convert wastewater nutrients to struvite would give farmers a sustainable alternative to the application of manure.

FEATURE



STORY BY **KURT PFITZER**

LEHIGH ESTABLISHES **DEPARTMENT** OF **BIOENGINEERING**

LONGTIME PROGRAM DIRECTOR TO SERVE AS FOUNDING CHAIR AS INTERNATIONAL SEARCH FOR PERMANENT CHAIR LAUNCHES

LEHIGH UNIVERSITY HAS ESTABLISHED A NEW DEPARTMENT OF BIOENGINEERING in the P.C. Rossin College of Engineering and Applied Science. The new Department will build upon Lehigh's popular bioengineering undergraduate and graduate programs, which were initiated in 2002 and 2009, as well as extensive interdisciplinary bioengineering research being pursued across the Rossin College and the University.

Professor Anand Jagota, a member of the Lehigh faculty and director of the Bioengineering Program since 2004, will serve as the new department's Founding Chair—and will assist in the University's recently-announced search for a permanent Chair to lead the department.

"The timing is right for Lehigh to recognize this evolution by organizing the faculty and students working in this space into a self-standing department." —Anand Jagota

The initial departmental faculty includes 17 members with academic appointments in the department and an additional 17 affiliated members. Their research is supported by the National Institutes of Health, the National Science Foundation, and the U.S. Departments of Defense and of Energy, among others. In keeping with the interdisciplinary nature of bioengineering, many of the bioengineering faculty members will have joint appointments in other departments in the Rossin College and in the College of Arts and Sciences.

Jagota says that the formal designation as a department reflects the importance of the field, as well as its emergence at Lehigh over the past 15 years.

"The field of bioengineering was born out of a combination of elements from other well-established disciplines," he says. "In recent years, it has developed its own language, its own tools, its own 'gravitational pull,' so to speak. Thus, the timing is right for Lehigh to recognize this evolution by organizing the faculty and students working in this space into a self-standing department."

According to Jagota, advances in molecular and cellular engineering, regenerative medicine, bioinformatics, imaging and analysis, biosensors and microfluidics, computational bioengineering, and related areas have fundamentally changed

the field's ethos over the past 15–20 years.

"Today's advances in bioengineering are coming largely from our improved understanding of molecular and cellular biology," he said. "Contributing in this space also requires a great depth of engineering knowledge to design systems, to perform analysis and to be quantitative at this level. These developments, along with parallel advancement in computing and information science over the same time period, have made the engineering perspective even more crucial in the field of human health and healthcare."

"The creation of the new Department of Bioengineering is an important advancement for our college and university," says Stephen DeWeerth, professor and dean of the Rossin College. "Biomedicine and health are among the most important areas for sustained growth in research and education across the engineering and computing disciplines. This importance is amplified at Lehigh, as we move toward the creation of a new college focused on integrated health. The bioengineering department will form an essential conduit for interdisciplinary partnership between the two colleges."

Through the new department, Lehigh will continue to grow its successful B.S., M.S., and Ph.D. programs in bioengineering and to expand its research in areas including biocomputation and modeling; diagnostics, sensors and devices; and materials and therapies.

"We have strong concentrations of people conducting research in devices, optics and microfluidics, and in biomaterials and biomechanics," says Jagota, "and we are building strength in biocomputation, data, and modeling."

Lehigh's Department of Bioengineering focuses on research related to computational and data science, such as Prof. Javier Buceta's approach to structural and computational biology (above); integrated biomedical devices for diagnostics and sensing, such as Prof. Yevgeny Berdichevsky's microwell chips for faster drug screening (opposite); and, materials and therapies, including Prof. Sabrina Jedlicka's research in implantable biomaterials (right).

DID YOU KNOW **that Lehigh graduate Philip Drinker, son of former President Henry Drinker, was a pioneer in the field industrial hygiene—the science of prevention and control of workplace health hazards and forebear to modern bioengineering? After earning a Master's degree at Lehigh in 1917, Philip helped found the Harvard School of Public Health, and embarked upon an illustrious career that contributed many of the era's most important advances in civil and military safety. He's best known for inventing the "iron lung," the famed mechanical respirator that saved countless lives at every major U.S. hospital during the polio epidemic of the 1930s.**

MATHEMATICS

STORY BY **RICHARD LALIBERTE** • PHOTOGRAPHY BY **DOUGLAS BENEDICT**

SWARMING DRONES, SELF-DRIVING VEHICLES, AND THE ALGORITHMS THAT LIGHT THE WAY

ANY DRIVER KNOWS THE BIGGEST PROBLEM ON ROADS: OTHER DRIVERS. Each independently—and with highly variable skill—pilots a vehicle weighing an average of two tons at high speed in a complex environment that includes road conditions, weather, obstacles and the constant jockeying of other cars and trucks. Drivers ideally keep plenty of space between them to allow reaction time in case of erratic or surprising developments.

The advent of self-driving cars may minimize some of the risks associated with driver inconsistency. Rather than battling a chaotic jumble of people ranging from sedate slowpokes to crazed speed demons, you may someday—perhaps sooner than you think—belong to what's called a platoon of cars that travel in a self-regulating group. Each car would communicate with cars nearby so they'd be attuned to what others are doing and be able to maneuver optimally to reach a given destination in the most efficient amount of time possible.

He and other Lehigh researchers are at the forefront of research into complex systems dealing with constantly changing variables—an area important to development of robotics, automation and machine learning. "There's great interest in these areas at Lehigh," says Subhrajit Bhattacharya, assistant professor of mechanical engineering and mechanics, who explores motion planning and control of autonomous, intelligent systems. "What's happening here is very exciting."

DISTRIBUTING CONTROL

Crucial to a system's integrity, autonomy and efficiency is how it's controlled. And distributing control across multiple agents can make a network more robust in responding to local failures. Take the example of drones, which can be flown in networked arrays—sometimes referred to as swarms—that have a variety of potential applications such as traffic reporting, surveillance and military missions.

IN MOTION

"We envision a team of high-speed, driverless cars, safely distanced from one another, traveling from city to city," says Nader Motee, associate professor of mechanical engineering and mechanics. "The most desirable feature for these networks is long-term autonomy. Yet this independence introduces the concepts of risk and fragility."

Risk and fragility, in fact, are key areas of Motee's work in design, control and optimization of distributed control and dynamical systems. "When we're talking about the kinds of systems where you have a group of agents—self-driving cars, drones, power plants—aiming to work as a team to accomplish a task, we're talking about networks," Motee says. "These are highly dynamic systems where a small time delay or an incorrectly computed response to an external disturbance can lead to catastrophic consequences."

Relying on a central control system such as a ground-based command center introduces potential vulnerabilities. "Each agent needs a communication channel with the base, which may be far from where the drones do their mission," Motee says. "If for some reason there's a failure at the base—power outage or hackers get into the central server—then all the drones are in trouble." Fragility is high.

Distributing control among the agents shores up some of these weaknesses. "If drones don't communicate to a central base but are just in touch with their neighbors and make decisions using local information, you can endure loss of one drone and still go on with the mission because the remaining drones continue to exchange information among each other," Motee says. "The network is less fragile and uncertain events become more tolerable."

Nader Motee with Ph.D. students Yaser Ghaedsharaf and Shima Dezfulian, adjunct professor Babak ShirMohammadi, and Ph.D. student Arash Amini (l to r, above); Subhrajit Bhattacharya and students develop algorithms that guide the motion of robots and other devices and vehicles (opposite.)

FORESEEING UNCERTAINTY'S OUTCOMES

Yet vulnerabilities remain. Part of what can make systems fragile is what researchers call noise—variables from outside the system that can degrade performance or make agents fail, increasing the risk that remaining nodes will also fail in a domino-like cascade. A car platoon that hits a road obstacle might suffer a collision that becomes a pileup. A fleet of drones flying south to north that hits a strong east-west wind might get thrown off course.

Sensing and communication become important elements in overcoming noise—but too much communication between agents becomes its own vulnerability. "As agents talk more and establish more communication channels, noisy information circulates more and gets amplified across the network," Motee says. So does the potential for intruders to hack the network and disrupt signals.

> *"Using our framework, relevant features can be abstracted away from these domain-specific applications into dynamic models suitable for risk and fragility analysis."* —Nader Motee

"You want to minimize the number of talking points across the network by dropping communication links but at the same time not lose performance," Motee says. This process, known as sparsification, presents difficult mathematical problems related to identifying where a system is most likely to fail and which channels between which agents should be used. "We have come up with some tractable algorithms to solve this inherently difficult problem," Motee says.

One approach is to use randomized algorithms. "We randomly pick a pair of agents and drop their communication channel, but in a way that allows performance of the network to remain the same," Motee says. So while performance doesn't drop, complexity does.

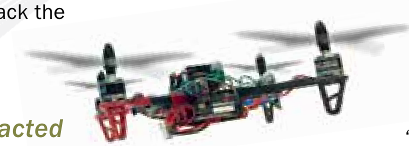
Motee and his students have also developed a computational framework based on systemic risk measures that can be applied to design a wide variety of networks. Systemic risk measures allow for constraints and uncertainties to be treated in terms of safety margins instead of exact requirements.

"Our methodology allows for all these seemingly different problems to be viewed in a rather unified manner," Motee says. "Autonomy and fragility issues in self-driving cars are different from drone problems, which are different from smart-grid problems, but the mathematical challenges are similar. Using our framework, relevant features can be abstracted away from these domain-specific applications into dynamic models suitable for risk and fragility analysis."

IN THE COLISEUM

Motee's lab is now researching advanced control capabilities in a 4,000-square-foot Lehigh space known as the 'Flying Machines Coliseum.' It's equipped with a high-precision motion capture system, a central server, a wireless communication network, and custom software that can monitor drones and provide information about their location in space along with dynamical measures such as the roll and pitch of each quadcopter in a networked array.

One new initiative is to design drones that can fly and navigate on their own by learning from what they see—without the aid of GPS. "This is particularly useful in providing fast and reliable information for emergency or search and rescue operations, or even reconnaissance missions," Motee says. "These drones can navigate through collapsed structures or even hazardous conditions with radiological, biological or chemical contamination."



Motee's team is developing a design methodology to optimize drone size, flight controller, and on-board sensors by integrating and co-designing control, navigation, and vision algorithms. "We blend tools from control theory, probabilistic modeling, computer vision, and embedded systems," he says. "We aren't as focused on the drones themselves or planning their motion as we are on understanding long-term autonomy for a wide range of dynamic network applications."

Motee's work is funded through grants associated with his 2016 Office of Naval Research Young Investigator Program award, as well as his 2015 National Science Foundation CAREER award.

MAPPING MOTION

A self-driving car needs to know where it's going from the start of its journey to the finish and the exact route to travel at every moment along the way. If the road curves, it needs to steer through the turn; if people are in the middle of a street, it needs to avoid them. "This is not only an engineering problem, it's a mathematical problem," Bhattacharya says. "Motion planning finds a sequence of action in the system's configuration space."

A rudimentary way to compute the motion of a robot navigating on a plane is to construct a line between its start and goal points. But, for more complex systems, executing many forms of multidimensional motion that sound simple to the human mind quickly become difficult to describe in mathematical terms.

"Making a 10-segment robot arm move through space to grab the handle of a coffee mug while avoiding the bookcase beside the table requires a mathematically rigorous algorithm," Bhattacharya says. In dynamic systems, motion complexity sometimes outstrips computational capacity to calculate it. "You have to find abstractions of these spaces that are computationally manageable," Bhattacharya says.

One tool for constructing such abstractions is topology—a branch of mathematics that analyses the characteristics of a configuration space and motions in it. A computational tool in topology is simplicial complexes, which build on traditional graph representations but add dimensionality. "Simplicial complexes offer much richer descriptions of configuration space," Bhattacharya says. "The unifying idea is to create simpler spaces where it's more feasible to do motion planning and come up with solutions that are optimally correct."

Optimal motion planning has wide applications. Some of Bhattacharya's work involves developing algorithms that determine how a pair of boats with a flexible boom or cable could navigate the ocean autonomously while avoiding collisions or entanglements with obstacles like buoys or other boats—potentially useful for automated oil-spill cleanup, where self-guided boats would collect and separate floating oil patches on the water's surface. Bhattacharya has also developed motion-planning algorithms for guiding robots in hazardous search-and-rescue tasks and law enforcement operations.

Bhattacharya joined Lehigh in 2016 after serving as a postdoctoral researcher in mathematics at the University of Pennsylvania, publishing work in the *International Journal of Robotics Research*, *Annals of Mathematics* and *Acta Applicandae Mathematicae*. "We're building an area that's relatively new, and Lehigh is a very good place to try out new ideas," Bhattacharya says.

SMALL LIGHT, AND FAST

Ultimately, researchers expect their discoveries to have practical applications, and Joachim Grenestedt, professor of mechanical engineering and mechanics and director of Lehigh's Composites Lab, is adept at bringing ideas to physical fruition.

His projects have included a custom-built land-speed racer that he piloted on Utah's Bonneville Salt Flats and an unmanned aircraft designed for perpetual flight. They've also included a 29-foot, two-seat speedboat made of stainless steel and composite materials built to study bottom slamming—the forceful, repetitive belly flopping of a boat as it moves at high speeds in waves.

Now, in a complementary project, Grenestedt's lab has built 10 small, unmanned, all-weather watercraft that can operate autonomously. Called Lehigh Ocean Research Craft Autonomous (LORCA), they were designed to measure ocean waves responsible for high slamming loads on fast-moving craft. "LORCA boats work like wave buoys, but because they move they can be used to get better measurements of wave propagation directions," Grenestedt says.

Constructed of carbon-fiber composite and measuring about four feet in length, LORCAs are small and light enough for a single person to carry and launch virtually anywhere. "The rounded deck makes them self-righting," Grenestedt says. "We can launch them upside down and they immediately turn right-side up." Once on open water, a brushless, in-runner electric motor driving a submerged propeller on a straight shaft can propel the boats to maximum speeds of more than 50 mph.

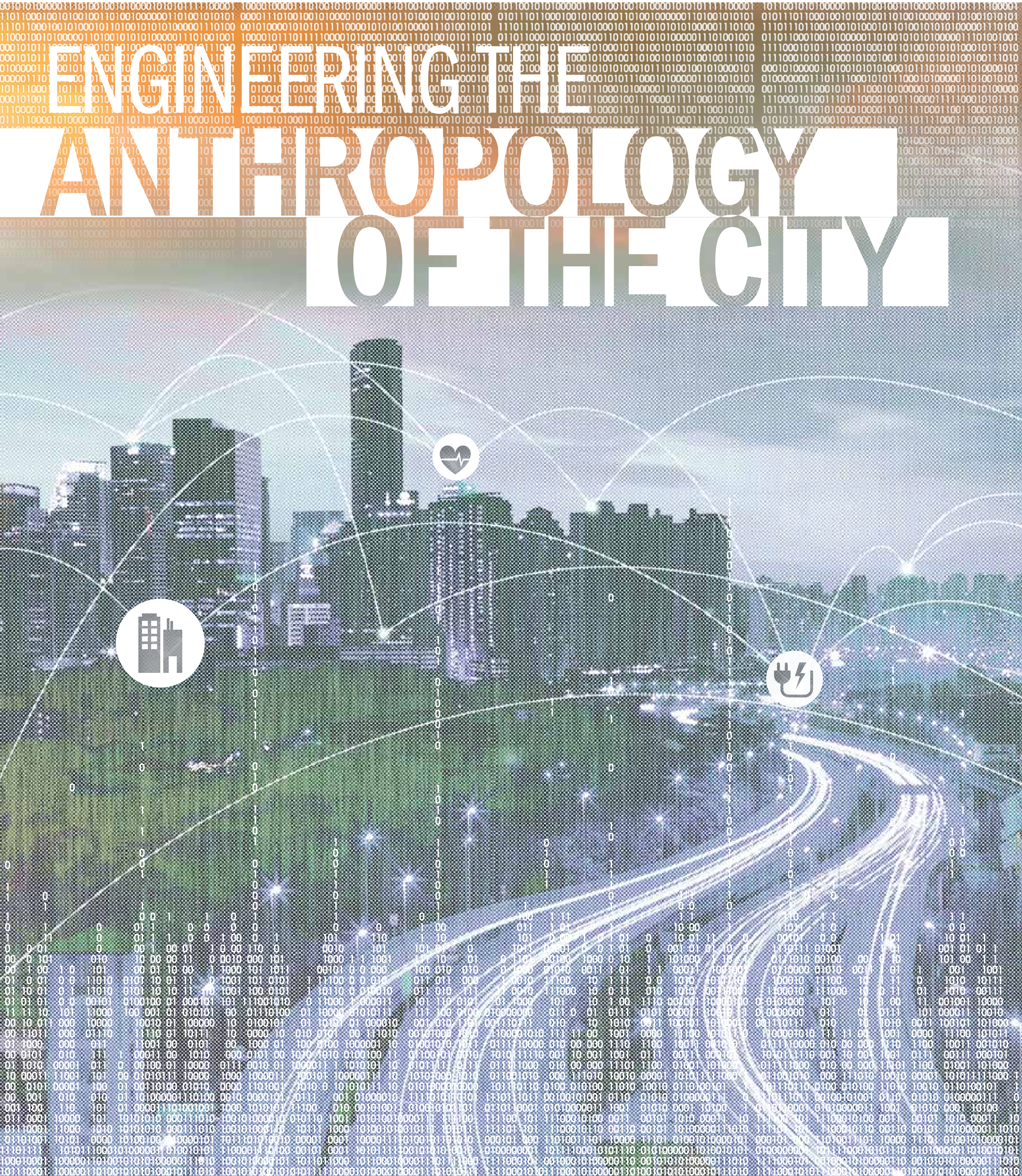
Hardware development and manufacturing was funded in part by the Office of Naval Research, while a Lehigh Collaborative Research Opportunity (CORE) grant helped fund autopilot software and systems developed by John Spletzer, associate professor of computer science and engineering, and his students.

LORCAs are capable of using waypoint navigation, in which Google map data downloaded to boats can be correlated with specific times that boats can be instructed to arrive at given points along a route. "Once we provide that information, we can let them go without any more human input," Grenestedt says.

So far, LORCAs aren't equipped to sense their environment or avoid obstacles with any form of automated intelligence—but the kind of research Lehigh's Nader Motee and Subhrajit Bhattacharya are doing in systems control and motion planning could help foster such advances.

Grenestedt speculates that small, unmanned watercraft could have wide applications beyond wave research. Possibilities include dropping them from aircraft in search-and-rescue operations and using them for law enforcement or military purposes such scouting rivers, conducting anti-piracy operations or monitoring international water borders. "I think only imagination—and the shoreline—will limit what unmanned boats can do," Grenestedt says.

ENGINEERING THE ANTHROPOLOGY OF THE CITY



STORY BY **CHRIS QUIRK**

RESEARCH EMPOWERS SMARTER CITIES AND MORE CONNECTED COMMUNITIES

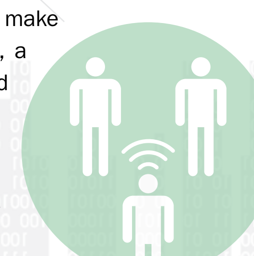
THE MENTION OF SMART CITIES MAY BRING TO MIND VISIONS OF A SPARKLING FUTURE METROPOLIS, CHURNING SMOOTHLY AND SILENTLY: gleaming monorails gliding by with nary a whisper, walkways whisking pedestrians to their destinations, wireless and instant access to information on demand, and lights brightening and dimming on cue as you enter or leave a room.

The reality of the smart city will be considerably grittier and far more complex, but a reality it will be—of necessity.

A 2014 United Nations report projected that the global urban population would rise from 54 percent in 2014 to 66 percent in 2050. Much of that growth will take place in disadvantaged areas ill-equipped to accommodate the greater numbers and density of people. As urban populations rise, efficiencies will have to be identified in expanding the finite elements of urban infrastructure. There will be commensurately greater wear and tear on energy, communication and transportation systems. The vital mechanisms that make cities habitable are going to come under increasingly severe duress.

Environmental concerns, like pollution and disease, as well as the planetary climate peril that looms, are further drivers in the urgent quest to create better and more connected 21st-century cities. Cybersecurity will be of paramount importance, as more and more of the systems that run cities come online.

The technological advances now being developed to make communities more connected will demand, in tandem, a rethinking of how people interact with and in cities, and how to best use the new technologies to improve human life. In creating the smart cities of the future, researchers will have to fundamentally address, and will in turn change, what Shalinee Kishore calls "the anthropology of the city."



Kishore, a professor in the department of electrical and computer engineering, is referring to the myriad ways people relate to the elements of a city, and the symbiotic process by which those elements shape the daily lives of its citizens.

“We view smart cities as adaptive systems, where interaction between the city’s infrastructure and humans is modeled as a continuous feedback loop and enabled by a supporting cyber-system,” explains Hector Muñoz-Avila, professor of computer science and engineering. “The infrastructures are themselves connected sharing information, which derives from infrastructure interdependencies, enabling cities to adapt to changes to over time. This includes long-term changes such as population growth and short-term immediate responses such as severe weather events.”

Connected communities will herald new opportunities to increase public safety, clean the environment, enable urban farming and on-demand manufacturing, and create as yet unseen avenues to entrepreneurship that will further accelerate the cycle of change. During the minutes spent on the bus commuting to work, in interactions with civil government, inside within the four walls of their homes, city dwellers will see the shape of their lives shift. And as they interact with the city’s mechanisms, use its infrastructure, and communicate with each other—via their actions, mobile and personal devices, and computers—citizens will provide information that will alter the systems of the city.

“YOU HAVE TO CONSIDER ALL THE VARIOUS LEVELS, DOWN TO THE GRANULAR. THERE ARE ALSO COMPONENTS THAT LIE OUTSIDE THE ENGINEERING WORLD THAT CANNOT BE IGNORED.” —Shamim Pakzad

But the task of creating successful smart cities is gargantuan. Researchers will have to find a way to integrate information from power plants, bridges, tunnels, means of transport, home appliances and everything in between. The data from sensors and devices will have to be communicated reliably and securely to data centers, which will analyze the information. Necessary actions or notifications will have to be transmitted to traffic control devices, buses and trains, power grids, homes and health care facilities. To top it all off, none of these systems will work optimally until their elements are connected and interdependent.

Kishore is one of a team of Lehigh researchers seeking solutions in what it calls “Smart Infrastructure for Connected Communities,” or SI2C for short. And although the team’s approach includes focused engineering needs in this space, it also addresses broader systemic and policy issues that can hinder these complex systems from running smoothly. It’s a big picture approach that tackles overarching problems and creates solutions that can be transferred across particular applications.

The scope of SI2C projects demands teamwork and combining the expertise of researchers conversant in different fields. “Due to the complexity of the problems, we need a big tent,” says Shamim Pakzad, associate professor of civil and environmental engineering. “You have to consider all the various levels, down to the granular. There are also components that lie outside the engineering world that cannot be ignored and that add difficulty. There is no best way to do this.”

One of the most important elements to smart city development is energy, in no small part because improved energy efficiency and utilizing renewables generally offer the greatest number of additional benefits, like cost savings and a cleaner environment. At Lehigh, the Integrated Networks for Electricity research cluster is uniquely resourced to address the matrix of problems that surround the creation of these systems. Besides being a dynamo for innovation in energy provision, the team of diversely-talented researchers is attacking policy, industry and other questions integral to supplying power to large, condensed populations.

Another major energy project at Lehigh is designing small, local grids across urban areas. These microgrids must attach to the comprehensive electric transportation system in order to provide citizens with power when necessary.

“There is an interaction there, and we have to determine how the grid can best supply power to the microgrid when needed,” Kishore explains. “Conversely, when the microgrid is operating in ‘island’ mode, we want to see if there is sufficient power to use for a public transportation infrastructure as its passes through the area.”

Modeling is a key tool at this stage for examining how a functioning smart city in all its complexity might operate. By overlaying models of the transportation, energy, communication

and other systems, researchers can map the interdependencies of the systems and see where weaknesses are most likely to appear, as well as how the systems will change over time. For example, if modeling identifies an area that's subject to electricity losses, additional resources may need to be deployed to support its power grid; plus, the city would want to avoid scheduling grid-powered busses in that area.

"The goal is to get to the point where we're analyzing real time data in terms of solar generation and traffic congestion in a given urban area," says Kishore. "Right now we're modeling and designing the best system. Later we want to see how the system would function in real time."

Richard Sause, the Joseph T. Stuart Professor of Structural Engineering and director of Lehigh's world-renowned Advanced Technology for Large Structural Systems (ATLSS) Center, also works on SI2C issues from the conceptual level to the tangible.

"These are cyber-physical systems, physical structures with integrated software and data components—the system is not just sitting there by itself," he says. "The cyber aspects of the system are used to optimize how the system works. A smart house won't operate unless you are processing data about the house. It's how we elevate people's experience in the house."

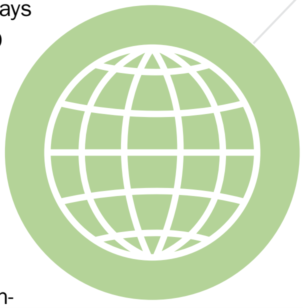
Pakzad offers the example of a bridge: "You have a $20,000 car, which has hundreds of sensors on it. You know everything about the car. You drive it over a billion-dollar bridge that has no sensors and tells you nothing. That is unacceptable. We want to bring all of these sensing systems and information-gathering mechanisms to the cities, collect the data, extract information, and make that work for the improvement of the services and interaction of the citizens with the cities."

"THESE ARE CYBER-PHYSICAL SYSTEMS, PHYSICAL STRUCTURES WITH INTEGRATED SOFTWARE AND DATA COMPONENTS—THE SYSTEM IS NOT JUST SITTING THERE BY ITSELF." —Richard Sause

Harnessing data to improve lives

Dig a little deeper into the smart bridge idea and the complexity and difficulties of the bridge system become obvious. Thousands of sensors on the bridge would replace human inspection. Multiply that number by the quantity of bridges, tunnels and similar infrastructure items in need of monitoring for maintenance in a city, and you have a data problem that presents a challenge for humans to evaluating in real time.

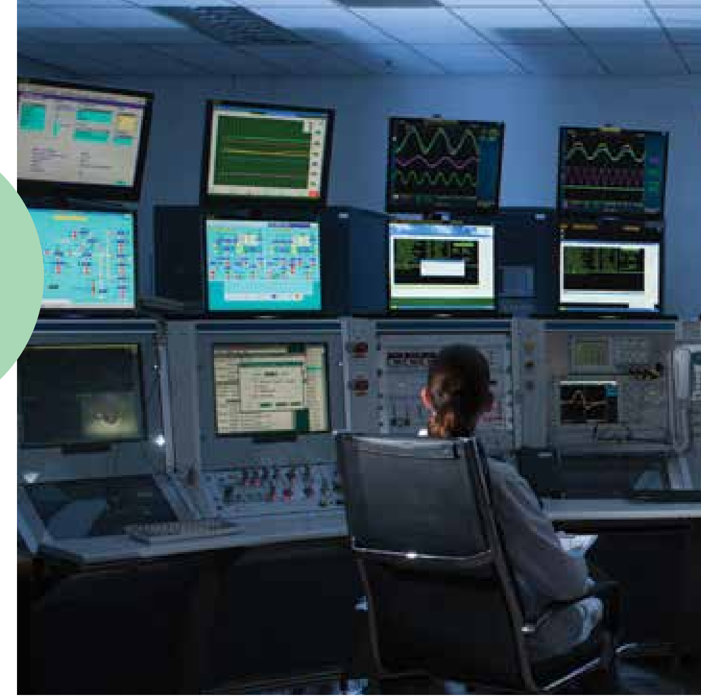
Muñoz-Avila designs intelligent systems which will be vital to making large-scale information networks function, and avoid small pitfalls that can cascade into a big nuisance. "What if you have an alarm on your bridge sensors that will just alert a human when it detects something suspicious. It sounds straightforward, but in reality this never works," says Muñoz-Avila. "Even if the sensors are accurate 99 percent of the time, this could mean a human is getting an alarm from a sensor dozens of times a day. A one percent error rate is very large in this case."



Take a situation where a sensor is pinging a warning to the control center. In the smarter systems Muñoz-Avila designs, the system would test itself automatically, instead of passing a warning straight through to a human supervisor. The system would immediately investigate the neighboring sensors and direct their focus toward the pinging sensor to double-check the reading. If the initial reading is confirmed, then a human is alerted to the potential problem. If not, the system can flag that sensor for inspection.

"We also will need to train these machine learning algorithms to understand what is normal, and to understand that 'normal' can change over time," says Muñoz-Avila. "Up to a point, degradation won't require maintenance, and there are regular seasonal changes that will fall well within the safe range of the components. If the system isn't trained to this, those sensors will start pinging after a year, and in a big city, that will cause a lot of headaches."

Researchers at work with Lehigh's hydrodynamic testing facility; Shamim Pakzad and students conduct tests in ATLSS (Above, l to r).



Another key component in the equation is the nature, volume and quality of the data that goes into SI2C systems. Besides infrastructure components, data added by the people who use the services enriches the reservoir of information markedly.

"The human in the loop is critical," says Kishore. "Human beings, with all of our devices, generate a lot of data that is relevant, but it is not typically captured as part of the design of an infrastructure system. Our devices are packed with sensors that are used for certain, limited tasks, yet could provide another important stream of data about the structure. If gathered through some sort of 'crowdsourcing,' this data can be just as useful as information streaming in from a sensor network."

Not just gathered, but squeezed like a grape, Pakzad says. "We want to make sure that data is used to full advantage in improving the lives of citizens."

Crowdsourced data could expand and improve the functions and services of a smart city. Imagine efficiently transporting fans home from the ballpark. The fans want more trains arriving at the mass transit stop nearest the game, but the system operators can only guess when

"WE ALSO WILL NEED TO TRAIN THESE MACHINE LEARNING ALGORITHMS TO UNDERSTAND WHAT IS NORMAL, AND TO UNDERSTAND THAT 'NORMAL' CAN CHANGE OVER TIME." —Hector Muñoz-Avila

the final 'at bat' will occur. Using crowdsourcing, the system could track mobile devices at the park and react as soon as masses of people began heading for the exits.

"There's a possibility of optimizing some services with crowdsourced data, which is really not so much about the hardware and infrastructure so much as the operational logistics of it," Sause explains. "Researchers keep coming up with more and more ideas the further we delve into this field—we've barely scratched the surface."

Most smartphones are minimally equipped with a camera, microphone, gyroscope, compass, an ambient light sensor and GPS functionality. Researchers could riff on these capacities to create new services as Sause describes.

"The cost of these sensors is now almost zero, so developers are happy to put whatever you might want on the phones to enable new applications," says Pakzad. "The reason that they don't have ten more sensors in them is because there is no current need. Sensors to transmit temperature or air quality data are a couple of potentially useful future possibilities as well."

Cybersecurity looms large, since smart city systems have to be open to the web to operate, which makes them inherently vulnerable to attack by malicious actors. Some vulnerabilities, like spoofing GPS timestamps on power grid data signals, are well known and notoriously easy to pull off. Others could be sophisticated attacks that will have to be anticipated or repelled in short order. Current best practices advocate a balance of firewalls and internal controls, says Kishore.

"In GPS spoofing, which is one of many such examples, you know some of the data is correct, but then you've got other data measurements that are telling you something different. So, we need to correlate all that data together to compare. Is one of the data points off? Are a hundred off? Whatever that scale of the attack is, you need to be able to find it and deal with it decisively."

Privacy issues go hand in hand with cybersecurity concerns. If data from users is critical to making smart cities work, data collection must be done anonymously and it must be protected.

"The value of the data is not in who generated it, but about the other information that you can get, as long as that is kept private," says Pakzad. "Many current apps, like traffic apps, work on the principle that consumers find the tradeoff between anonymously sending location data in exchange for information on how to avoid snarled traffic an acceptable one."

"At the community level, smart connectivity may well be an attractive feature," says Sause. "It could even be a draw for businesses or people, and so there could be incentive for communities and governments to find ways to get it done."

Kishore is involved in a multifaceted project that offers a sense of the tip-to-tail demands and possibilities in this research space. The project involves a combination of two types of water systems, water filtration and hydroelectric turbines situated in the Hudson River's tidal estuary. As water is

being drawn in to be filtered for usage, it will generate power for distribution across the region.

“The optimization specs for the design and sensors is rich with interrelated components,” she says. “We are looking at the filtration side, pulling out the brackish water, and there is a whole cybersystem and sensor system being set up to monitor that. The purification mechanism will look at pollutants and the quality of the water coming into the system in real time, and modify operating settings accordingly.”

On the power-generation side of the project, there is an economic component being addressed by faculty from Lehigh’s College of Business and Economics interested in the process of bidding into energy markets. “How does a tidal power generator make bids on the market when they only generate power four times a day? What’s the best strategy for a firm like this?” asks Kishore.

According to Muñoz-Avila, the cross-disciplinary culture at Lehigh in particular makes it a fruitful place to develop answers for tomorrow’s urban communities. “I have been at Lehigh for about 15 years, and one thing that always makes me feel great is the low barrier between the disciplines,” he says. “I have the freedom to devote a lot of time to interdisciplinary work, and that is exactly what is needed to create smart cities—people from multiple disciplines working together.”

Honors from IEEE

RESEARCH RECOGNITION

Professor Rick Blum, who holds the Robert W. Wieseman Research Professorship in Electrical Engineering, has been named as a 2018 Distinguished Lecturer of the Institute of Electrical and Electronics Engineers (IEEE) Signal Processing Society. This prestigious recognition from IEEE, the world’s largest technical professional organization, helps to connect well-known educators and authors in the field to IEEE chapters around the country to support networking and the sharing of new knowledge.

Blum began his teaching career as an assistant professor in 1991, coming to Lehigh from his position as senior communications and digital signal processing engineer at General Electric Aerospace. His research projects at GE included communication systems modeling and simulation, VLSI research and development, beamforming algorithm research and communication link simulation tool research. A full professor at Lehigh since 2002, Blum’s research interests remain in the area of signal processing and communications theory.

Currently, Blum leads a team from Lehigh’s Integrated Networks for Electricity research cluster in a new research center that aims to develop new technologies to protect the nation’s power grid from cyber attacks. The center, made possible by a $12.2 million grant to Lehigh and four other universities from the U.S. Department of Energy, is helping develop and test new technologies that will modernize and secure the U.S. electrical power grid.

$3.5 million of that funding will support Lehigh researchers as they develop technologies that will protect the grid from cybercriminals and similar threats. Lehigh’s work focuses on five distinct areas that nine faculty members—the largest concentration of investigators in the project—approach from a variety of perspectives. These include detecting attacks, mitigating attacks that can’t be identified, managing security systems, and testing and validation—including the discovery of false data.

The Lehigh team is developing algorithms and optimization tools that, for example, could detect, measure, and compare redundant signals at multiple locations in the grid.

“The INE research cluster has done really well in the five years it’s been in existence,” Blum says. “But research into the energy infrastructure is broad work, here on our campus and elsewhere, and progress will require a lot of interconnection. With a strong interdisciplinary work ethic already in place, Lehigh is well positioned to help lead the way.”

OPENING DOORS

ROSSIN COLLEGE SEEKS TO IMPROVE DIVERSITY OF LEHIGH'S ENGINEERING COMMUNITY

STORY BY
MANASEE WAGH

Bruke Mammo and Kristen Mejia are members of the first graduating class of Greer Scholars.

In her four years as a Lehigh engineering student and Greer Scholar, Kristen Mejia '17 thought often of her parents.

"My mom's from the Dominican Republic and my dad is from Honduras," says Mejia. "They grew up living hard lives, and their stories about not having clean water always moved me. I feel privileged to be here."

The Greer Scholars program in the P.C. Rossin College of Engineering and Applied Science supports students from underrepresented groups. Mejia was one of six Greer Scholars to earn engineering degrees last spring.

"We're all very supportive of one another despite being from different backgrounds," Mejia says. "If I had gone to any other school I don't know that I would have graduated in engineering, because the way I think about problems is nontraditional."

Mejia earned her B.S. degree in IDEAS (Integrated Degree in Engineering, Arts and Sciences), a program that allowed her to craft her own course of studies. She plans now to study public health and solve the kinds of water issues her parents experienced.

One of Mejia's friends is fellow Greer graduate Bruke Mammo '17.

"We're all doing wildly different things," says Mammo, "and it's amazing to see where we're all going after graduation." Mammo interned for Twitter after completing a B.S. in computer science and business (CSB) and returned to Lehigh in the fall to pursue an M.S. in computer science. He hopes to work in machine learning in Silicon Valley.

Now in its fifth year, the Greer Scholars program has 59 students, with a new cohort of 16 that joined Lehigh this fall.

"This program has really helped in terms of recruitment and retention of students of color," says Henry Odi, deputy vice president for equity and community.

Overall, the share of traditionally underrepresented groups in the Rossin College student body and faculty has increased, thanks to efforts including the Greer Scholars, ADVANCE, and CHOICES programs, the Society of Women Engineers, and the Lehigh chapters of the National Society of Black Engineers and the Society of Hispanic Professional Engineers.

The ADVANCE program was launched in 2010 with a five-year grant from the National Science Foundation and is now supported by Lehigh. This collaboration between the ADVANCE Center and the Provost Office has led the Rossin College to think deeply about hiring practices for faculty, resulting in workshops to ensure that searches for new faculty are conducted in ways that promote diverse groups of candidates. A typical search involves 100 to 200 candidates, says Ray Pearson, professor of materials science and engineering.

"We're striving to have our faculty hiring pools reflect national demographics," Pearson says.

The Rossin College has been hiring more women and taking concrete steps to retain them, says ADVANCE staff director Marci Levine.

"With programs like this, you risk creating a revolving door if the campus climate doesn't change along with the hiring policies," says Levine, "and we have seen a positive shift here at Lehigh. Retention is where we're likely to see a bigger impact as we move forward."

The college has created a support system for female faculty members, who meet monthly to discuss professional development, student mentoring, time management and work-life balance, said ADVANCE faculty director Kristen Jellison, associate professor of civil and environmental engineering.

"These meetings develop a sense of community among women faculty. We learn about the issues that are really important for women on our campus, which helps us focus our efforts in the right direction," she says.

Mentoring programs for recently tenured associate professors and newly hired assistant professors keep the engineering school in touch with the faculty climate. Male faculty members act as "advocates" and "allies" to support their female peers.

"The men in these roles have been amazing," Levine says.

"The ADVANCE grant [now known as the ADVANCE Center for Women Faculty in STEM] has done a great deal to help the College recruit and retain

more women faculty," says Odi, "but we are working hard to diversify our faculty racially."

Pearson says that efforts toward diversifying the student body take many forms.

"There's a curricular component," he says. "Lehigh's interdisciplinary approach in engineering, which gives rise to programs like IDEAS and CSB that combine modes of thinking, seems to naturally interest a more diverse set of young minds," he says. "And of course programs like the Greer Scholars help make college an attainable goal, especially for first-generation students. But there are also steps we can take to inspire STEM pursuits long before the college essays are being written."

One of these is the Rossin College's longstanding CHOICES program, which encourages middle school girls to consider studying engineering or science through hands-on, challenging, team-based engineering projects.

During both the CHOICES weeklong summer camp and the daylong program in the spring, volunteers from Lehigh's Society of Women Engineers (SWE) choose experiments, act as mentors, and arrange for panel discussions with professors and industry leaders.

By performing fun experiments, the middle schoolers learn the applications of some of each field's basic disciplines. And by working with the SWE mentors, they get to see what women engineers look like.

"CHOICES demonstrates to girls that they can be anything they want to be," says Lori Cirucci, who teaches science at Broughal Middle School in Bethlehem, Pa., and sends students to CHOICES each year. "My students recognize that engineering is very doable for them and not just a guy thing."

GREER SCHOLARS PROGRAM

9	59	UP TO 20
2017 GRADS	STUDENTS ENROLLED	NEW STUDENTS EACH YEAR

Heather Schenk, a 2011 Lehigh engineering alumna and Air Products chemical engineer, volunteered with CHOICES as a student and returns to the university each year to help with the program.

"This is a valuable opportunity for women to experience engineering when they're younger," says Schenk. "Programs like CHOICES challenge stereotypes about engineers while giving girls the chance to see women engineers and imagine themselves in that role. I love coming back to these events and helping to make the girls super excited about the possibilities of engineering."

ENGINEERING A DIFFERENT PATH

Launched in 2013, the Greer Scholars Program provides funding and a support network for African American and Hispanic students pursuing engineering studies at Lehigh. Initiated through the philanthropic efforts of DR. CARL '62 and PAT GREER, close to 90% of the nearly 60 Greer Scholars have remained in engineering—a dramatic improvement, says Carl, on the roughly 30% of his Class of '62 engineers who stayed the course. Mr. Greer, a "career alchemist" of sorts, has lived many lives since graduating from Lehigh as a metallurgical engineer. He's been a finance professor, an oil executive, as well as an author, clinical psychologist, Jungian analyst, and shamanic practitioner. Based in Chicago, Carl and his wife, Pat, also a Jungian analyst, supervise the Greer Foundation, which supports alternative-healthcare programs, shelters for abused women and children, and many other causes. "Engineering is a good way for young African Americans, Hispanics and Native Americans to approach life," says Carl. "It provides a good mental discipline that can lead to high-paying jobs."

Keith Moored's work in fluid dynamic interactions has earned him an NSF CAREER Award.

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In the swim

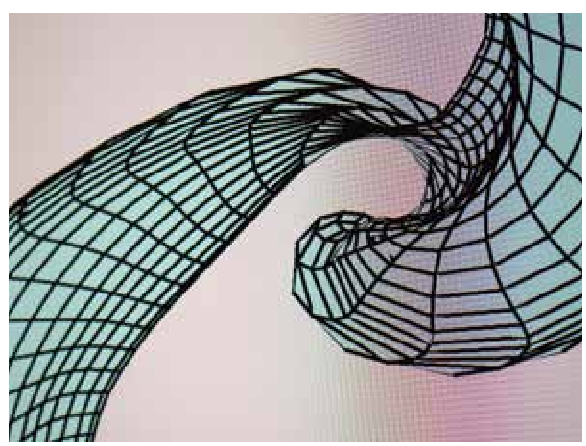
Bio-inspired technology for the world beneath the waves

If you've ever been to an aquarium, you've likely lost yourself staring into a sea of blue at an array of varied and exotic underwater creatures.

You observe their colors and marvel at the way each species interacts with others, but have you ever paused to consider the unique ways these animals move through the water?

Keith Moored certainly has. "I once attended a fluid mechanics conference that took place at the Long Beach Aquarium in California," he says. "Everyone in bio-propulsion, including myself, invariably ended up lost in thought, staring at the fish."

Moored, an assistant professor of mechanical engineering and mechanics, studies bio-propulsion—movement by legs, fins, wings, and other muscles instead of mechanical means—since his time as a student at the University of Virginia. It's also the focus of the prestigious CAREER Award he recently received from the National Science Foundation.



Ultimately his work could answer the question: What can scientists borrow from nature to achieve teams of aquatic vehicles as optimized for underwater movement as fish swimming in a school? Gaining a comprehensive understanding of these collective interactions could help scientists determine how fragile biological networks are to overfishing, loss of habitat and a changing climate. It could also open the door to the development of schools of bio-inspired technologies.

"As an undergraduate, I studied aerospace engineering and physics," he says. "As my Ph.D. work began, I started on a project to develop a bio-robotic device that would swim like a manta ray."

The manta's large, morphing fins are designed to enable swift and efficient movement, characteristics his research adviser wanted to explore as a way to improve aircraft wings. The project, which was funded by the U.S. Department of Defense as a Multidisciplinary University Research Initiative (MURI), allowed Moored to apply both his knowledge of mechanics and his love of marine life to a project with wide-reaching military and civilian application.

This work also led to other projects he would join as a faculty member at Lehigh with the goal of improving underwater robots so that they look, sound, and move exactly like fish.

Designing for depth

"When we design aircraft, we know how much lift should be generated and how much drag is being produced, but underwater it is a totally different world," Moored says. "Design equations for efficient aquatic bio-robotics simply didn't exist—how could we unlock the basic science so that engineers could build more reliable robots? Developing those equations was our job. I have always loved the water and aquatic animals, so this felt like the perfect way to connect my passions and make an impact—putting their secrets to work for us."

Among other civilian and military applications for this work, Moored says, is a need to better observe and track fish without disrupting their habitat.

"From a biological perspective, learning more about underwater species is challenging because current technology tends to scare away a lot of fish," he says. "And often, in terms of speed or the amount of energy the robots can carry with them, our machines just can't keep up with them."

For his CAREER project, Moored is continuing to study bio-propulsion in fish, but he's applying it to the way they move collectively. His project focuses on extending our knowledge of the fluid dynamic interactions that occur in animal collectives: flocks, schools and swarms. The overarching research goal of the program is to understand the flow mechanisms that occur among unsteady, three-dimensional interacting bodies in complex arrangements.

"The key to making a breakthrough in the design of high-performance collectives of bio-inspired devices is to understand the fundamental fluid mechanics of collective interactions," Moored explains. "But right now we don't have a thorough understanding of the fluid dynamics among schools of fish."

Moored says dynamic interactions occur between multiple fish that change the mechanism by which each individual swims as fast and efficiently as possible. "In previous research, we've found that the fluid dynamics between fish in groups creates forces between them. These fluid-mediated forces cause fish to arrange themselves naturally, kind of like atoms in a lattice-like structure," he says. "If they break position, the forces pull them back."

He hopes the project will lead to further advancements in underwater biotech, including the development of schools of bio-inspired robots that can perform more complex tasks than single swimmers.

But underwater life is only part of Moored's research focus. He also has an eye toward the sky, as he works on several projects in the Unsteady Aerodynamics Laboratory in Packard Lab with airborne applications.

One project is funded through the U.S. Army Armament Research, Development and Engineering Center. "I'm working on this with Terry Hart, a retired astronaut and a fellow faculty member in our mechanical engineering department," Moored says. "We're developing a gun-launchable unmanned aerial vehicle (UAV) that can survey the area around buildings or over hills on the battlefield."

Moored has a device that flies right now, but he and the team have more work to do in order to improve performance—"to make the UAV fly higher, faster, and for longer," he says.

EXCELLENCE HAS NO FINISH LINE

Team Baja, supported by the Rossin College Experiential Learning Fund, is just one of the broad variety of opportunities around campus for Lehigh engineering students to connect what they learn in the classroom to the real world, and to discover their passion through international experiences, faculty-led research, and team-based projects.

Make your gift to the Rossin College Experiential Learning Fund today!
Visit **give.lu/rossin** or use the enclosed, postage-paid envelope.

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OPENING DOORS

Programs such as the Greer Scholars and Lehigh Women Engineers help to improve the diversity of Lehigh's engineering community.

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