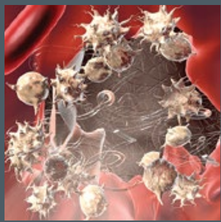

USING LIGHT TO PIN PLATELETS

Group discovers new domain in protein vital to blood clotting.

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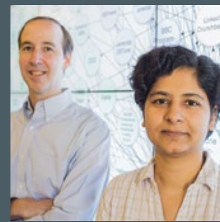

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A SWAT team boosts search speeds, recall and precision.

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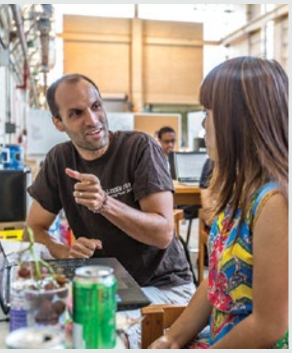

COVER STORY
A new initiative will expand the computer science and engineering department while infusing data analytics across Lehigh's curriculum. *See page 10*

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LEHIGH UNIVERSITY

Finding lessons in the data

Welcome to the 18th 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.

It is a distinct honor to serve once again as interim dean of the P.C. Rossin College of Engineering and Applied Science. I am focused on encouraging and uplifting the collaborative spirit that is crucial in the modern engineering landscape—and key to continued discovery and innovation across our College's educational and research endeavors.

I've been at Lehigh for more than 25 years and have served since 2002 as associate dean for research and graduate studies. Over that time, I've grown to admire and respect the integrated approach to learning and research that has become the hallmark of Lehigh Engineering.

Nowhere is that approach more evident than in the emerging Data X initiative, which is featured in this issue of *Resolve*. While it will significantly expand Lehigh's capacities for teaching and learning in computational and data science, Data X will also increase access to this knowledge base for all Lehigh students, regardless of their major.

Through Data X, Lehigh is recruiting new faculty in computer science and in related fields across Lehigh's colleges, building new bridges to industry, and infusing the art of data analysis throughout all areas of study.

We are also thrilled to host the 14th International Semantic Web Conference in mid-October—another strong indicator of Lehigh's growing reputation in the computer science community, and of the Lehigh Valley's emergence as an innovation incubator within striking distance of New York, Philadelphia, Boston and Washington, D.C.

This issue also delves into our longstanding and highly successful Computer Science and Business undergraduate program. In describing the program, its co-director, Prof. Hank Korth, says it best: "CSB is for students who want to make technology happen, not just cope with it."

Other articles cover recent successes of junior faculty who are making progress in their respective fields, including National Science Foundation CAREER Award recipients Nader Motee, Bryan Berger and Arindam Banerjee. We also sat down with Allan Frank '76 '78G '79G, the City of Philadelphia's first Chief Technology Officer, to find out how local government can leverage technology to benefit its constituents.

"Lehigh is recruiting new faculty in computer science and related fields to infuse the art of data analysis throughout all areas of study." —John Coulter

There's also news of some important research collaborations, including work with DuPont Corporation, the Department of Energy and Stevens Institute of Technology. From vanquishing hospital-borne "superbugs" to biomass fuels, and from network theory to the spread of Ebola to the impact of friction on machine parts, Lehigh researchers are finding new ways to create value and benefit industry and society.

I hope you enjoy this issue of *Resolve*. Please drop me a line with your thoughts and comments.

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Taking aim at bacterial virulence factors

Antimicrobial drug resistance is pervasive throughout U.S. hospitals, due in large part to a drop in new antibiotics being approved. As a result, potentially deadly infections have evolved stronger resistance to existing antibiotics, especially in hospitals, according to the National Institutes of Health (NIH). Ninety thousand patients who develop an infection in the hospital die each year, as compared to 13,300 in 1992.

"The problem of antibiotic resistance is terrifying," says Angela Brown, assistant professor of chemical and biomolecular engineering. "My goal is to find an alternative to existing antibiotics. Very few new molecules are employed in the fight against bad bacteria, and existing antibiotics are being prescribed more frequently, which leads to more drug resistance."

Most pathogenic bacteria produce some type of virulence factor as they settle into their new home, such as a toxin that kills host cells, enzymes that convert host cell molecules into nutrients for the bacteria, or molecules that allow bacteria to bind to surfaces. Instead of looking for new compounds that kill bacteria directly, Brown wants to block this mechanism so the body's immune system can knock bacteria out before they become a threat.

As a postdoc at the University of Pennsylvania, Brown and her colleagues investigated the toxin-producing properties of *Aggregatibacter actinomycetemcomitans*, which causes periodontitis.

In a 2012 article in the *Journal of Biological Chemistry*, Brown identified the mechanism that the bacterium employs to bind to cholesterol and kill white blood cells. Using surface plasmon resonance and differential scanning calorimetry, her team measured the leukotoxin's interaction with cholesterol.

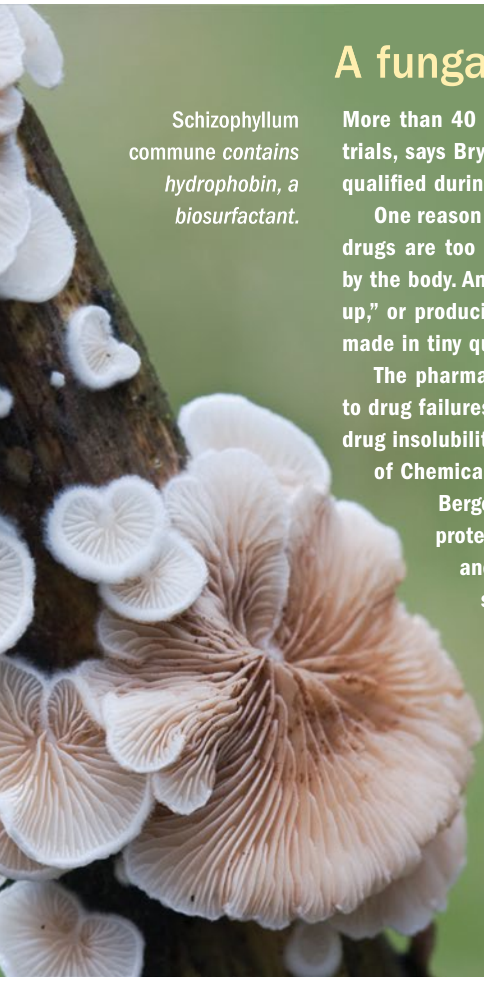
"Our goal is to see if we can prevent these toxins from killing the immune cells," she says. "We hope to do this with other bacteria as well."

With a grant from NIH, Brown and her students have created a peptide chain of 20 amino acids that binds to cellular cholesterol, blocking the identically shaped toxin chain from occupying the space.

Someday, Brown hopes, success in test tubes with individual cells will translate to a method of blocking virulence factors in all kinds of harmful bacteria, bypassing traditional antibiotic drugs altogether. It's past time to find a new way to beat this invisible enemy, she says.

"Bacteria will always find a way to resist. If we don't keep up with them, we could have a really big problem."

A fungal fix for drug insolubility



Schizophyllum commune *contains hydrophobin, a biosurfactant.*

More than 40 percent of potential new drugs fail in preclinical trials, says Bryan Berger, and another 30 to 40 percent are disqualified during the first phase of clinical testing.

One reason for the low success rate, says Berger, is that many drugs are too insoluble to be absorbed in sufficient quantities by the body. Another stumbling block is the difficulty in "scaling up," or producing large quantities of a substance that is easily made in tiny quantities in the laboratory.

The pharmaceutical industry loses millions of dollars a year to drug failures but has struggled to find a biocompatible fix for drug insolubility, says Berger, the P.C. Rossin Assistant Professor of Chemical and Biomolecular Engineering.

Berger believes he can boost drug solubility with a protein called hydrophobin that is found in mushrooms and other fungi. The hydrophobin would act as a surfactant by reducing surface tension between liquids and solids. By controlling hydrophobin's pH, Berger believes he can also target the drug to diseased sites in the body. And by genetically reengineering the bacteria E. coli, he hopes to produce a drug in commercially viable quantities.

Berger recently received a CAREER Award from NSF for a project titled "Scalable Synthesis of Designed Biosurfactants to Enhance Drug Bioavailability." Surfactants, which occur naturally and can be made synthetically, are used in detergents, mouthwashes and other solutions to improve water's cleaning ability. Surfactants contain both water- and oil-soluble components and thus have the ability to solubilize a variety of chemicals in solution. And surfactants can act as emulsifiers by stabilizing oil-water interfaces.

One of Berger's goals is to learn how to alter the structure of biosurfactants—surfactants made from biological sources—in order to improve drug solubility while preventing unwanted side effects.

Currently, says Berger, about 90 percent of patented medications contain surfactants. One of the most common, Polysorbate 80, also known by the brand name of Tween 80, is a petroleum-based compound valued for its low cost. Because it can cause severe allergic reactions, skin rashes and other side effects, scientists are seeking to make biocompatible alternatives that are more environmentally friendly.

"Our goal is to make proteins that mimic Tween's ability to formulate drugs, and that are nontoxic and scalable," says Berger. "Tween is dirt cheap because it is petroleum-based. Our solution has to be cheap, scalable and effective in order to be competitive."

Hydrophobin, a protein discovered in 1991 in the common mushroom *Schizophyllum commune*, offers a biocompatible alternative to Tween 80. Benign, nontoxic and prevalent, hydrophobin is used commercially for coatings. It is difficult to produce cheaply and in large quantities, but Berger believes his group has overcome that challenge.

Shining a stochastic spotlight on Ebola

Researchers seek to concentrate healthcare resources where they are most needed.

The Ebola virus disease, which kills as many as 70 percent of the people it infects, has claimed more than 11,000 lives in the West African nations of Guinea, Sierra Leone and Liberia in the past year. Scientists believe the virus originated in 1976 in the Democratic Republic of Congo, nearly 3,000 miles away, and that it is carried—and transmitted to humans—by bats.

Such a scenario, says Javier Buceta, associate professor of chemical and biomolecular engineering, raises a number of questions. What aspects of their behavior determine whether and how bats become infected? How do bats infect humans? How does the virus travel such a distance?

And what steps can humans take to prevent an outbreak or halt its spread?

Because these questions involve so many random variables, Buceta is seeking to develop computational models that measure the probability that a particular result or results will occur.

Buceta and Paolo Bocchini, assistant professor of civil and environmental engineering, were recently awarded a one-year Collaborative Research (CORE) Grant from the Office of the Vice President for Research to apply stochastic modeling to the spread of Ebola.

They hope to use their model to develop more effective methods of predicting, mapping and responding to disease outbreaks and natural disasters, and in the long term to collaborate with social scientists and economists.

Buceta has spent years modeling the spread of the Hantavirus, which is carried by the deer mouse and can cause potentially fatal diseases in humans.

"When I first started reading about Ebola," he says, "I realized there weren't many models of the bats that carry the virus. I came up with the idea of developing stochastic models to study the dynamics of the infection of the bat population.

"Many factors affect these dynamics, including environment, climate, migratory habits and availability of resources. If bats have to fight for food, this increases the chances they will infect each other. Another factor is seasonality and the fact that bat babies may be the main carriers.

"To understand the systemic behavior of the bat population, you have to sample all of these variables."

Bocchini develops stochastic models to analyze the effects of earthquakes and other natural disasters on an infrastructure network such as a city's bridges. The models help anticipate how much damage will occur and where it will occur, possible effects on traffic patterns, and which bridges will most likely need to be shut down.

Buceta and Bocchini hope to "rigorously quantify the risk associated with the spread of a virus over a large geographical area [and] to perform probabilistic cost-benefit analyses and concentrate resources to fight an epidemic.

"For such a model to be useful in terms of its predictive capabilities," the researchers say, "we must be able to quantify the effective probability that an outbreak will develop at particular locations. This requires adequately sampling a very large space."

Functional quantization (FQ) will make it possible to obtain "hazard maps" that show the probability of Ebola reaching a community for a given set of initial conditions.

"When I started talking with Javier about random functions," says Bocchini, "I realized that some of the mathematical tools I use to describe natural disasters could be applied to sample the spread of the Ebola virus.

"Javier's tool attempts to predict how a virus will spread. My goal is to develop probabilistic methods to support decisions such as the allocation of resources."

Ronald A. Ross won the 1902 Nobel Prize in medicine for using mathematical modeling to link mosquitoes to malaria outbreaks. But no model has yet been developed that can forecast the outbreak and spread of Ebola while accounting for the size of the area it affects and the randomness of the variables involved.

This sampling will be done using a methodology called functional quantization (FQ), which was developed to study fluctuations in the stock market.

"FQ provides an optimal representation of an entire stochastic space using a small number of samples that are carefully selected and weighted to truly capture all possible configurations," the researchers say. "It will make it possible to obtain 'hazard maps' that show the probability of Ebola reaching a community for a given set of initial conditions.

"This type of constantly evolving information will allow authorities to react promptly to the diffusion of the disease and concentrate available resources where they can be most effective."

Crossing a critical threshold

Researchers solve a long-standing problem in optical communications.

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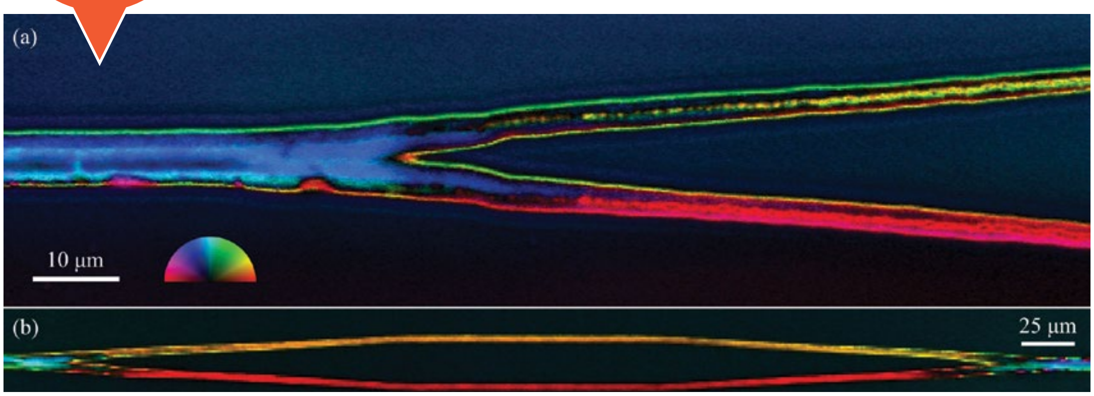
Researchers from Lehigh, Japan and Canada have advanced a step closer to all-optical data transmission by building and demonstrating what they call the "world's first fully functioning single crystal waveguide in glass."

In an article published in May in *Scientific Reports*, a *Nature* publication, the group said it used ultrafast femtosecond (fs) lasers to produce a 3D single crystal capable of guiding light waves through glass with little loss of light.

"Other groups have made crystal in



A polarized light field microscope image, says Jain (right), shows crystal junctions written inside glass with a femtosecond laser. Upon divergence (a), independent lattice orientations develop in each branch and are retained (b) as the branches merge back into a single line. The color wheel indicates the angle of the fast or slow axis of birefringence.

glass but were not able to demonstrate quality," says Himanshu Jain, professor of materials science and engineering. "With the quality of our crystal, we have crossed the threshold for the idea to be useful."

The group patterned crystals in glass by employing lasers that emit pulses lasting from a few fs to hundreds of fs. One fs is one-quadrillionth (10^{-15}) of a second.

Scientists are seeking to make crystal in glass in order to prevent light from being scattered as it is transmitted, says Jain. Glass turns to crystal when heated, but this transition must be controlled.

"The question is, 'How long will this process take and will we get one crystal or many?' We want a single crystal; light cannot travel through multiple crystals. And we need the crystal to be in the right shape and form."

The high intensity of the fs laser pulse, says Jain, enables the laser to achieve a precise focus, which allows researchers to control where the laser is focused and where light is absorbed.

"We can heat the glass only locally," says Jain, "creating the desired conditions and causing the glass to melt, or almost melt, until it is transformed into a crystal."

The laser's focus also makes it possible to "write" the crystal inside the glass and not on its surface.

"We want to write only deep inside the glass," says Jain. "Somehow, you have to get the laser inside the glass before you turn it on. We do that by exploiting a property of the fs lasers—that only at the focal point of the laser is there sufficient intensity to cause the change you want."

The group built its crystal in glass composed of lanthanum borogermanate ($LaBGeO_5$), demonstrated the crystal's waveguiding capabilities and quantified its transmission efficiency.

As a ferroelectric material, $LaBGeO_5$ offers critical advantages, says Volkmar Dierolf, chair of physics in the College of Arts and Sciences. "Ferroelectric crystals have demonstrated an electrical-optical effect that can be exploited for switching and for steering light from one place to another. Ferroelectric crystals can also transform light from one frequency to another. This makes it possible to send light through different channels."

The group says its achievement will boost efforts to develop photonic integrated circuits (PICs) that are smaller, cheaper, more energy-efficient and more reliable than current networks that use discrete optoelectronic components—waveguides, splitters, modulators, filters, amplifiers—to transport optical signals.

"A major trend in optics," the researchers write, "has been a drive toward…replacing systems of large discrete components that provide individual functions with compact and multifunctional PICs."

To make this transition, they write, improved methods of fabricating 3D PICs are needed. "The methods currently employed for fabricating PICs are photolithographic and other processes suitable for planar geometries. 3D PIC fabrication techniques would enable a much higher density of components and much more compact devices, while at the same time creating opportunities for new technologies such as high density 3D optical memory."

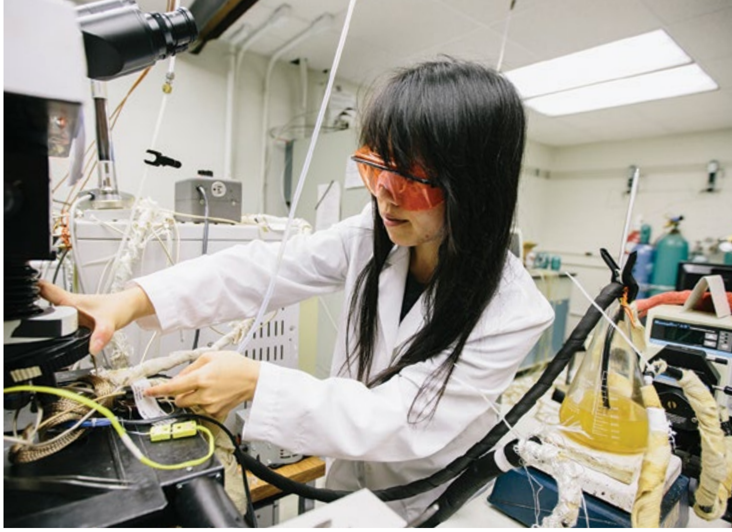
To fabricate 3D PICs, say the researchers, it is necessary to prevent light from scattering as it is being transmitted and to transmit and manipulate light signals fast enough to handle increasingly large quantities of data. Glass, with a disordered atomic structure, cannot do this. Crystals, with a highly ordered specific lattice structure, have the requisite optical qualities.

"Photonic applications that not only transport but also manipulate photonic signals…require crystalline substrates with second-order nonlinear optical response," the researchers write. "The ability to pattern nonlinear optical crystals in glass is therefore essential for 3D laser-fabrication of PICs to achieve its full potential."

The article is titled "Direct laser-writing of ferroelectric single-crystal waveguide architectures in glass for 3D integrated optics." Its authors are Adam Stone '14 Ph.D.; Jain; Dierolf; and researchers from Kyoto University and Polytechnique Montreal.

Streamlining the conversion of natural gas

Researchers describe a critical reaction at the molecular level.



Researchers from Lehigh and the Stevens Institute of Technology have improved the fundamental understanding of a catalytic reaction that converts natural gas into liquid fuels and chemical industry feedstocks.

Writing in *Science*, Israel E. Wachs of Lehigh and Simon Podkolzin of Stevens and their students reported a molecular-level description of the reaction, which employs catalysts with molybdenum nanostructures supported on shape-selective zeolites.

Their achievement, the researchers wrote, "opens new opportunities for the rational design of improved catalyst formulations and for optimizing the reaction conditions" for the conversion of natural gas.

Using spectroscopy techniques, the researchers identified the initial Mo nanostructures and their anchoring sites on the zeolite. They interpreted the experimental results using quantum chemical and molecular mechanical modeling calculations. The study was funded by NSF.

The rapid deactivation of the molybdenum catalyst has been one of the biggest obstacles to its commercial use in the liquefaction of natural gas. Wachs and Podkolzin demonstrated that this deactivation can be reversed and catalytic activity fully restored. They also showed that the distribution of the molybdenum nanostructures can be controlled, enhancing catalytic activity.

Natural gas is often produced when oil is drilled, say the researchers, but much of it is discharged into the atmosphere.

One technology being developed to address this challenge is the conversion of natural gas into liquid aromatic hydrocarbons in a single step. Dehydroaromatization offers advantages over other methane activation chemistries because it does not require oxidizing reagents, say the researchers.

By characterizing the catalyst under reaction conditions, the researchers say they were able "to determine the identity and anchoring sites of initial Mo oxide nanostructures and establish a relationship between the identity of molybdenum nanostructures and catalytic performance."

The key to preventing deactivation of the catalyst and enhancing its performance, they say, is to reverse the formation of carbonaceous deposits and growth of Mo nanostructures under reaction conditions while controlling the anchoring sites of the structures.

Yadan Tang '14 Ph.D. studied the molybdenum nanostructure catalysts in Lehigh's Operando Molecular Spectroscopy and Catalysis Laboratory, which is directed by Wachs.

From biomass to useful products

Rare earth metals catalyze cellulose into chemical building blocks.

A rare-metal catalyst can streamline the processing of biomass into sustainable materials and fuels, an international research group reported recently in *Nature Communications.*

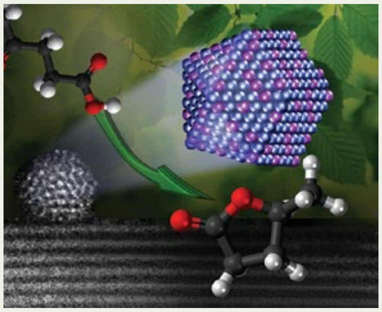
The group said the catalyst of ruthenium and palladium nanoparticles on a support of titanium dioxide achieved the conversion of levulinic acid (LA) to gamma-valerolactone (GVL), a key reaction in the processing of biomass into usable products.

Led by chemists at Utrecht University in The Netherlands, the group includes researchers from Lehigh and from the UK Catalysis Hub of the Research Complex at Harwell and University College London, both in the United Kingdom.

The group said it had "managed not only to speed up a crucial intermediate stage in the processing of biomass, but also to make it more efficient. The result...can subsequently be converted into a variety of valuable renewable products, such as plastics and fuels."

Biomass can be converted into heat or biofuels and holds potential as a clean source of renewable energy. It is generated from switchgrass, corn husks, straw, forest foliage and other nonedible plants.

To use biomass as a fuel, says Christopher J. Kiely, professor of materials science and engineering at Lehigh, scientists must first convert its chief component—cellulose—into chemical building blocks and in turn to usable products.



Using a modified impregnation technique developed by Kiely, the Utrecht researchers fashioned the Ru-Pd catalyst on a TiO_2 support. Qian He '12 Ph.D. imaged and chemically analyzed the Ru-Pd nanoparticles with Lehigh's world-class aberration-corrected electron microscopy facilities.

During processing, the cellulose in biomass is degraded into the organic compound levulinic acid (LA) and then hydrogenated into gamma-valerolactone (GVL), a chemical building block that can be converted into fuels, solvents, plastics and perfumes.

The Ru-Pd catalyst formulation developed by the group converts LA into GVL much more efficiently than other metal catalysts that have previously been tried, says Kiely.

"Catalysts," says Kiely, "should be highly active and efficiently convert reactants to products. They should be specific and generate primarily the product that we desire. Finally, they should be stable so they can be reused without diminishing their activity and selectivity.

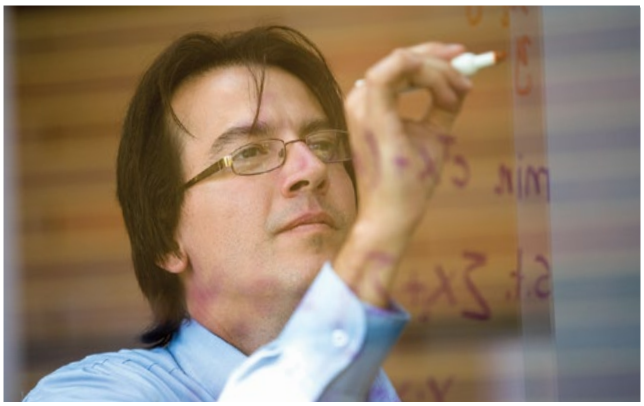
"We have hit all three of these targets. The Ru-Pd catalyst is very active, it very selectively makes GVL, and it's very durable.

"Other catalysts are being tested for this key reaction but they're either unstable or they're inefficient at converting reactants into products. The optimized metal combination—ruthenium and palladium—and the modified impregnation technique make for a stable and efficient catalytic process."

The black-and-white portion of this graphic, generated at Lehigh, shows an atomic-resolution electron microscopy image of two Ru-Pd catalyst particles, measuring 1-2 nm in diameter, on a TiO_2 support. The colored portion, computer-generated at Utrecht University, shows the conversion of LA to GVL along with renditions of the Ru-Pd nanoparticle and renewable biomass.

The shaping of solutions to come

Mathematical optimization provides robust algorithms to find the best answer to decision-making problems that can be described using linear, discrete or convex equations on the problem's decision variables. For



example, it allows utility companies to find the lowest-cost mix of power plants to meet a given demand for electricity. For these algorithms, convexity is critical.

But what happens when you factor in the real-world physics of the electrical grid, and the need to balance the wear-and-tear of ramping generators up and down with the availability of relatively inexpensive renewable energy sources? Modeling these types of phenomena in decision-making problems requires non-convex equations. Moreover, using algorithms for linear, discrete or convex problems in these cases, leads to solutions that might not be best for the problem at hand.

Simplifying the equations of nonlinear phenomena so that decision-making problems can be solved with robust computational techniques already in place is the forte of Luis Zuluaga, assistant professor of industrial and systems engineering. NSF, the U.S. Air Force and the Pennsylvania Infrastructure Technology Alliance (PITA) have supported Zuluaga's efforts.

Zuluaga's NSF work centers on the mathematics of finding the best way to model complex physics in optimization problems. "You can construct mathematical problems that are simple to solve and give an approximation of reality," he says. "I am working to make better approximations."

Researchers already have algorithms, says Zuluaga, to solve problems that can be framed as the interaction of linear relationships, such as that between the capacity of generators and the demand placed on them.

Modeling the transmission losses and variable routing across the electrical grid, however, "is a highly nonlinear problem," Zuluaga says, represented by functions that undulate and have many local minima and maxima that are difficult to solve for.

A common approach is to develop more complex algorithms to solve such problems. Zuluaga, however, reframes the situation in terms of polynomial expressions that can be quickly solved using tried-and-true algorithms for linear and convex problems. Instead of developing more solution algorithms, this technique, called "convex optimization," simplifies the problem so it fits existing methods.

Zuluaga is working to expand this method to difficult problems such as deciding when the costs of ramping generators up and down outweighs the savings from using cheap renewable sources. With its variable conditions—the weather, the distance from a power plant to a wind or solar farm—this kind of problem contains multiple peaks and valleys in its mathematical representation that can't be solved by traditional convex techniques.

Zuluaga's technique carves the problem into one that can be solved using convex methods. His research explores the tradeoffs inherent in this process.

UAVs and banks and the mathematical ties that bind

A cell is a dynamic, complex arrangement of nucleic acids, proteins and molecules that work together. An electrical grid connects wind and solar farms to homes and businesses with generating stations and transmission lines.

If one component fails in either system—cell or grid—the entire system can crash. A town might experience a blackout if a falling tree severs an electrical line.

Nader Motee, the P.C. Rossin Assistant Professor of Mechanical Engineering and Mechanics, studies the conditions that cause complicated networks to collapse. Besides cells and power grids, he examines networks of banks and of unmanned aerial vehicles (UAVs). Each system has components, or nodes, that act in concert by exchanging large amounts of data with other nodes.

"All of these systems have distinctly different problems, but they follow the same mathematical laws," says Motee, who recently received a CAREER Award from NSF. His goal is to formulate a unified theory that helps researchers make the networks more robust.

The coupling between two nodes in a system can be expressed as a line, says Motee. "If one bank gives another bank a loan, that's simple, draw a line between them. Now add in more banks that exchange money and depend on each other. As you draw more lines between banks, you make a graph, and it keeps getting more complex and more prone to failure."

Managing that complexity requires new mathematical tools and techniques.

"Over the past three years, we've been trying to come up with rules to make the best possible shape for that model graph. We have been able

A holistic interest in algorithms

In the age of Big Data and instant everything, says Martin Takáč, human activities are placing increasingly onerous demands on the invisible algorithm.

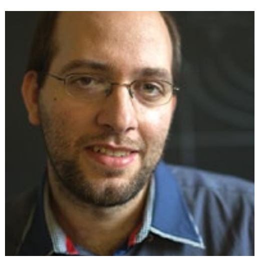
Algorithms today help us trade stocks and find vacation bargains. They feed us the news we want, guess our movie and music preferences, help us find spouses, and suggest Facebook friends.

To perform these tasks, says Takáč, an assistant professor of industrial and systems engineering, computers must solve huge problems encompassing hundreds of terabytes of data. To make sense of such a vast amount of data, algorithms must be able to harness the power of hundreds or thousands of computers simultaneously.

Takáč has a holistic interest in algorithms—in assessing their reliability and performance, in explaining and implementing them, and in using them to find optimal solutions to problems with billions of variables.

"My approach is to develop a theory that enables you to design a better algorithm and implement it so it can be run on a computer. It's also necessary to have a theory that tells you that an algorithm will always work and how many steps it will need in order to find a good solution.

> *"My approach is to develop a theory that enables you to design a better algorithm and implement it so it can be run on a computer."*
>
> —Martin Takáč



"We use software to develop an algorithm, then we test it and compare it to other algorithms. It is successful only if it passes all these tests. You can propose anything; it's quite another thing to propose something that will actually work better than existing algorithms and, moreover, to prove that it works."

In one project, Takáč is designing a distributed algorithm for classical machine learning problems like the email and spam problem.

"Let's say I need to go through thousands of emails in a short period of time, labeling them and assigning them to one category or another," he says. "To accomplish this, I might need to track 90,000 different key words, or features. I would assign negative values to words like *money* and *Viagra* and positive values to *Martin* and *meeting.*

"An incoming email that does not mention *meeting* or *money* but does mention *Viagra* twice might have a value of, say, -200, earning it a quick spam assignation. The next email might mention *meeting* once; it would have a value of +20 and is not spam.

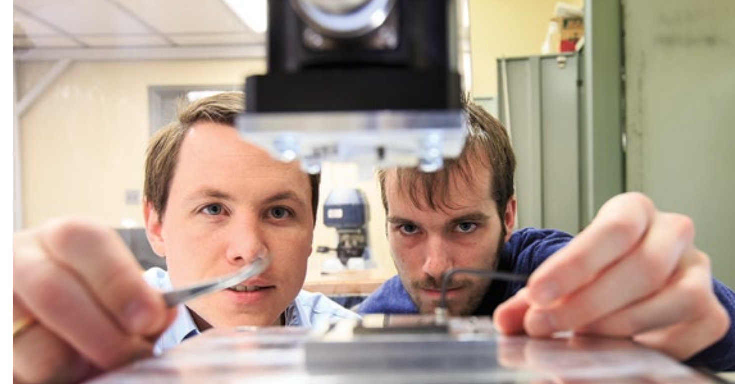
"Our task is to write an algorithm to find the values for every feature and then make predictions as to whether a large quantity of emails is spam or not."

Takáč's papers have been published in *Mathematical Programming*, the *International Journal of Numerical Analysis and Modeling, Advances in Neural Information Processing Systems* and other journals.

to prove that if you add a new link to a specific part of the graph, it works better. If you get rid of certain couplings, the risk of collapse increases. We are getting closer to figuring out how to reshape the overall network."

Nature, says Motee, is an inspiring source of information.

"We can learn from cell biology. Cells have been able to survive, under all kinds of conditions, for several million years. They must operate in a really efficient way. So far, our ideas are long shots, but we are hoping to find a common solution for all of these systems."



Nonfriction literature

Mechanical engineers team with DuPont to improve materials in sliding applications.

Wear and tear, some experts have estimated, can consume 2 to 6 percent of a nation's GDP. This comes as no surprise to Brandon Krick, an assistant professor of mechanical engineering and mechanics and director of Lehigh's Tribology Lab.

"Every single moving mechanical piece of equipment has sliding interfaces," says Krick. "Friction and wear are the number one reason these joints, bushings and bearings give out."

Krick and collaborators at DuPont Inc. recently received a grant through NSF's Grant Opportunities for Academic Liaison with Industry (GOALI) program, to study Teflon, the fluoropolymer coating for cookware. Teflon's relatively rapid rate of wear, Krick says, makes it unsuitable for sliding applications and impossible to be injection-molded into desired shapes.

Krick's group is making nanocomposites of alumina and dispersing them as filler in the Teflon polymer matrix to modify the matrix and reduce its melting temperature. The alumina nanocomposites, says Krick, interact synergistically with the Teflon polymer to facilitate chemical, physical and mechanical changes that reinforce the surface and improve wear resistance.

The group is working with two materials produced by DuPont—PTFE (polytetrafluoroethylene) and PFA (perfluoroalkoxy).

"DuPont has improved Teflon so it can be injection-molded but not for low-wear materials," says Krick. "We want to make Teflon wear-resistant and injection-moldable for both low-wear and longer-lasting materials."

Krick's students examine the origins of friction, wear, materials deformation and adhesion on complex surfaces ranging from cells to nanocomposites and in environments ranging from the vacuum conditions of outer space to thousands of feet under water. They conduct sliding experiments that can remove, on average, less than 1 angstrom of material per sliding pass, as well as larger amounts.

To measure friction and wear, the students build tribometers and use chemical analysis techniques such as infrared spectroscopy and X-ray photoelectron spectroscopy. The Tribology Lab also houses an optical profilometer that measures surface profiles in 3D at the nanoscale.

"We have been able to reduce the wear rate for Teflon by 10,000 times for sliding applications," says Krick. "Typically, industry has to replace worn-out parts too often. We can cut costs and reduce this waste."

Recently, Krick's group sent samples to the International Space Station, and its tribometers became the first to be directly exposed to the Low Earth Orbit Environment.

INTERVIEW BY **WILLIAM TAVANI** PHOTOGRAPHY BY **REBECCA McALPIN**

THE CITY AS A DATA-DRIVEN ECOSYSTEM

INFORMATION TECHNOLOGY IS CHANGING THE CULTURE OF MUNICIPAL GOVERNMENT.

Allan Frank is Chief IT strategist and cofounder of The Hackett Group, an intellectual property-based services firm specializing in benchmarking, research, business transformation and technology consulting with a global client base that includes 93 percent of the Dow Jones Industrials, 86 percent of the Fortune 100, 87 percent of the DAX 30 and 51 percent of the FTSE 100. Frank's many citations include the *Computerworld* Premier 100 Award. *InformationWeek* named him one of the top 10 U.S. technology innovators and *Philadelphia Tech* ranked him with the region's top 10 technology leaders. Frank served as Philadelphia's first Chief Technology Officer from 2008-11. He holds a B.S. in accounting (1976), MBA (1978) and M.S. in computer science (1979) from Lehigh.

Q: ***What role did you play as Philadelphia's first chief technology officer?***

A: There was a tremendous need for a real transformation to get the city's technology up to par. There were over 40 agencies and I had responsibility for IT across all of them. I had to come up with a five-year strategy and plan to modernize the operation and develop a set of programs. Plus, we needed remedial technology investment. So I developed a holistic program across the city to improve and expand technology within the context of the mayor's overall goals of efficient government, public safety, thriving community and economic development.

Q: ***What were your main accomplishments as CTO?***

A: First, we undertook a technology modernization program, everything from upgrading networks and servers to putting in new business applications. We worked on the tech sector, the startups, the creative sector, and supported collaboration with programs like Open Access Philly that bring together people across the broad tech communities. We also developed a consortium between the city and a number of not-for-profit institutions to deal with the digital divide and put computers in the hands of people who can't afford them. The consortium delivered about 5,000 computers across the city and also outfitted buses with computers to give people access.

Q: ***How is IT changing the way cities are managed?***

A: It's changing every aspect of city management. One interesting example that has broad impact across multiple services is this notion that everything in a city—every building, tree, street, street center line, pipe and piece of fiber—can be geocoded in geographic information maps. There are two million trees in the city for the parks and recreation people; thousands of buildings for building inspectors. How do city workers take care of all that? They can do it with geocoded maps. When a fire bell rings, firefighters can locate the type of house and the nearest hydrant and respond in minutes. We have all the data. It's just not connected.

Q: ***What kinds of cultural, procedural or technological change does the "Internet of Everything" require of municipal government?***

A: I saw my role not so much as government in the traditional sense but as leading an entire ecosystem of people, institutions, technologies and data. Technology is a "must have" capability in order to "run the railroad" of a city, but today it is also a key enabler to innovate new services and capabilities to serve citizens. The "Internet of Everything (IOE)" is really another way of describing the connectedness of people and things that has come about as computers, networks and software have become ubiquitous. A city is, in fact, the ultimate use case of IOE. Inside city government during my tenure there was a growing recognition of both the connectedness of everything and the power of Internet-fueled technologies. Today, cities are a living lab for leveraging the IOE to create a better world. Let's remember, inside government today there are many "millennials" who get it, and although we say the wheels of government turn slowly, when it comes to the use of technology, there is a growing recognition that the power of the Internet can change how government operates for the benefit of all.

Q: ***How can universities work with industry and government to connect citizens to services and information?***

A: I see a natural affinity between academic institutions and cities. We continually engaged with many colleges and universities and all for different purposes. With Penn, it was to provide consulting and advice to our leaders on how government operates. With Temple, it was to engage youth to help them look at the city differently and create apps that solve real problems for citizens. With Lehigh, we had a project with the Philadelphia School District to train principals.

Q: ***How can technology be utilized to protect our cities from cyber and physical attacks?***

A: As the fifth largest city in the U.S., Philadelphia is clearly a potential target for both cyber and physical attacks. There is a lot I cannot discuss about how technology can and is being utilized to protect the city. During my tenure, I was heavily involved in a number of very critical initiatives including deployment of hundreds of video surveillance cameras, creation of unique data-driven intelligence gathering capabilities, upgrading of networks, and the deployment of unique emergency communication capabilities. Even our water is monitored on a real-time basis. All this information tells us physical security is really about situational awareness, "knowing" what's going on and responding in real time. It's complicated and challenging, and it's getting harder every day.

Q: ***Can you trace the development of analytics from its early roots to today?***

A: The U.S. Department of Defense developed the Internet to allow scientists to share their work. In the 1990s it was put to commercial use through browsers that could traverse large databases. By the time we got to the 2000s, firms like Yahoo! and Google understood you couldn't make a computer big or fast enough to answer any query on the rapidly expanding Internet. They solved the problem by creating a solution that can scale data and search analytics by leveraging thousands of cheap commodity computer servers across the Internet and by creating software that breaks the analytics problem into thousands of parallel tasks that can be performed across the thousands of servers simultaneously. Today, this technology can be leveraged by any company or institution. It's called HADOOP and sometimes also referred to as a "Big Data" capability. That, in effect, is how we got to where we are today: Vast amounts of data, Internet-enabled through a global network of servers, powered by technologies and Internet-scale applications.

Q: ***Analytics is about interpreting multiple flows of data in real time. How do "smart cities" successfully navigate data and separate noise from meaningful insight?***

A: A city is veritable fountain of data. Every traffic light, building, tree, vehicle, crime, business, even our water supply generates critical data. There's a tremendous amount of data streaming in cities in real time—numbers, words, geocodes, audio, video. To separate meaningful data from the noise requires sophisticated computer science. We're getting better at it, but it's a never-ending challenge. However, I believe that most cities today see data analytics in all its forms as a key enabler.

Q: ***How can higher education help prepare students to thrive in a data-infused world?'***

A: IT touches everything and everybody. There's business, data science, computer science, statistics. It's incumbent on universities to make sure we see the connection points. That's where innovation comes from. Lehigh has always understood that you innovate by looking at the edges of disciplines. Solutions to our problems, innovations to move us forward, are in pattern matching. In any discipline, I always encourage people to look outside for new ideas and perspectives. That's what we need today.

Q How do open data initiatives influence the vitality of "smart cities"?

Open data is about transparency, democracy. It's at the pulse of urban life. Philly now has a dedicated role for the director of open data. Their Open Data website covers nearly everything that goes on in the city—art, culture, the budget, elections, policy, the environment, food. It lets you visualize the school budget or trends in your neighborhood. You can find out about tax delinquency, energy consumption, city contracts. It's invaluable to citizens and businesses. It encourages enterprise in the city. It's a great use of analytics.

Q: ***You also have skills and background in business. How important is that in managing cities?***

A: To find a better way to do anything you start with a specific goal and work backwards. I'm one of those people with one foot in business and one in technology, so I've always had this back and forth. There's a tremendous interest around analytics in the commercial space—finding revenue, pleasing the customer. Everything is driven by a specific purpose. City government is similar—you do everything to solve a problem.

Q: ***What attracted you to step away from your successful entrepreneurial and consulting career and go into municipal government?***

A: I saw the city as a "sandbox." It was an opportunity not just to deal with typical IT problems like keeping servers running, but to make a real impact. Philly is a city with more than 1.5 million souls geographically spanning over 170 square miles. I have often said there are not two flavors of cities anymore, ones with computers and ones without. Governments, schools, homes, businesses and institutions are all enabled by technology. In short, it's a key enabler for everything today. That thought is very intriguing and very attractive to me.

RIDING THE WAVE

VIEW THE VIDEO
LEHIGH.EDU/WAVE
Watch alumni and industry leaders describe the power of the data wave, and how Lehigh is poised to succeed.

STORY BY **CHRIS QUIRK**

HARNESSING THE POWER OF AN OCEAN OF DATA

THE SAVE FOR THE FINAL GAME OF THE 2014 WORLD SERIES went to the San Francisco Giants' pitching ace, Madison Bumgarner, but it took a software program to haul his bacon out of the fire.

The Giants were leading the Kansas City Royals 3-2 in the bottom of the fifth inning when they sent Bumgarner, their stellar starter, to the mound in relief. But Bumgarner gave up a leadoff hit, and the runner advanced to second base. With one out, Nori Aoki stepped up to the plate.

On a 2-1 pitch, Aoki sliced a line drive toward the corner in left field. It looked like a potentially game-tying base hit, but as the camera tracked the ball in flight, left fielder Juan Perez appeared out of nowhere, loped toward the foul line, and made a routine catch.

The TV analyst praised Perez but noticed something else. "Great jump, but look where they had him sitting. This ball off the bat looked like a double in the corner."

Ben Jedlovec, watching the game, smiled to himself. Jedlovec is president of Baseball Info Solutions, a leading baseball data and analytics company. Among his clients are 22 of the 30 Major League Baseball teams, including the Giants. Jedlovec, an adjunct professor in the College of Business and Economics (CBE), also teaches a popular class in sabermetrics at Lehigh.

"We have a product that shows that when Aoki hits the ball to the outfield," says Jedlovec, "he tends to slap it shallow and to the opposite field. That's why Perez was positioned way over near the line. If he's in a regular position on that play, it's a double and the run scores standing up. Instead, Perez makes it look easy."

The Giants won the game, 3-2, and the World Series, 4 games to 3.

The story of last year's Game 7, says Dan Lopresti, illustrates one of the countless ways that data analytics is solving modern problems. Advertising and crop watering, cancer treatment and epidemiology, Internet searching and climate forecasting are a few of the other applications. Indeed, says Lopresti, chair and professor of computer science and engineering, almost every area of modern life has benefited from the ability to interpret and harness the terabytes of data generated by digital technology.

Lopresti, an expert in pattern recognition bioinformatics and computer security, is also director of Data X, a new initiative that will infuse the teaching of computer and data science into all the university's colleges.

Launched earlier this year, Data X will initially support the hiring of 18 new faculty members in three colleges—12 in computer science and engineering and six more with expertise in consumer analytics, digital media and bioengineering.

The digitization of modern life

Data X will also help Lehigh meet growing student demand for courses in computer science and engineering, where enrollment has risen by 163 percent in five years. "During my senior year, I took a data mining course with Prof. Lopresti," says Glenn DuPaul '14, an economics major. "There were students from across Lehigh's majors; every seat was taken. We had to find a larger classroom. Data science and analytics is growing quickly, as is demand among students.

"People are saying that data is this generation's oil."

Lopresti says students in all academic fields need data smartness and computational thinking.

At the base of the new initiative, says Lopresti, is the explosion of data brought about in the last two decades by the revolution in digital technology and the Internet.

Data, says Lopresti, is generated by myriad devices—smartphones, tablets, PCs, traffic sensors, security cameras—that are connected to the Internet. Data mining, machine learning and search engines make data accessible; imagination and the ability to interpret that data are the key to transforming it into valuable, usable information.

"Many areas of life—from entertainment to TV, from music to our social interactions, things not formerly regarded as data—are now digitized and converted into bytes," says Lopresti.

"In the early days of the Internet, only a few computers were connected. Then it was millions. Now, we're approaching the point where every device imaginable will soon be connected to the Internet. This is creating an ocean of data."

It is also creating an opportunity—and an obligation—for the 21st-century university. According to government estimates, 1.4 million new jobs in computing will open by 2020, but only 400,000 college graduates will be qualified to fill them.

"Students today need data smartness as well as computational thinking to take advantage of this new mass of data," says Lopresti. "They need to understand data and how it can be useful. They need to understand algorithms, Internet connectivity and machine learning that can aid in analyzing this complicated, messy, incomplete data in real time. And they need the critical thinking skills that a top-notch liberal arts university like Lehigh can provide."

The data wave is creating demand for a new kind of interdisciplinary curriculum that combines data literacy with proficiency in other disciplines, says Lopresti.

"The sheer pervasiveness of technology has created enormous opportunity, along with a high degree of complexity, in nearly every discipline," says Lopresti. "You can no longer be educated in any one area without understanding the impact and the importance of data analytics in that field."

At the same time, he adds, "It is becoming much easier to incorporate computer science into other disciplines.

LEHIGH TO HOST ISWC, OWL CONFERENCES

More than 500 semantic web researchers will travel to Bethlehem October 11-15 for the 14th International Semantic Web Conference.

"ISWC is the preeminent conference that focuses on the semantic web," says Jeff Heflin, associate professor of computer science and engineering. "It has a history of presenting the very best academic work in the field while providing a forum to discuss applied use of semantic techniques and demonstrate new software applications."

Heflin worked with colleagues at Lehigh and with Discover Lehigh Valley to put together the winning bid to host the conference. The organizing committee has members from eight countries, and conference attendees will represent six continents. ISWC draws top academics, leading corporations, and representatives of governmental standards bodies.

Lehigh will host some of the same researchers at the 12th OWL: Experiences and Directions (OWLED) to be held at Lehigh October 9-10. That event aims to establish a global forum for the OWL (Web Ontology Language) community.

It's easier to use programming and other computing techniques. And young people are growing up using computers everywhere for everything."

Natural places for collaboration

Data X is designed to have a particularly positive impact on three academic programs—bioengineering, marketing, and journalism—while bolstering Lehigh's computational research and educational capabilities.

Anand Jagota, director of the bioengineering program, says data literacy is helping to spur innovation in the field.

"Point of care and diagnostic devices will lead to a new way of making diagnoses more personal, while hopefully reducing costs," says Jagota. "To do this, we need to deal with big streams of data.

"In addition, studying the properties of cell structure, and how molecules interact and fold are basic questions in bioengineering. The theoretical study of these phenomena requires very large computations and data visualization, so it's a natural place for computer science and bioengineering to collaborate."

Xiaolei Huang, associate professor of computer science and engineering, and Chao Zhou, assistant professor of electrical and computer engineering, analyze breast tissue images using optical coherence microscopy and tomography to produce computer-aided diagnoses. Their analysis is data-intensive, automated and designed to provide real-time information to help surgeons minimize the tissue they remove while operating on cancer patients.

"The process takes a large number of images, and labels the types of tissue in the sample," says Huang. "For every pixel in the image, we know whether it is fat, carcinoma, etc.

"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." The results, she says, are markedly superior to the visual diagnostic review that doctors generally use with current medical imaging.

Javier Buceta, associate professor of chemical and biomolecular engineering, and Paolo Bocchini, assistant professor of civil and environmental engineering, are developing a stochastic model to forecast the probable spread of Ebola. Buceta is an expert in modeling biological systems; Bocchini focuses on the response of infrastructure to earthquakes, fires and other disasters.

"Although Paolo and I have very different outcomes in our individual research," says Buceta, "we speak the same mathematical and computational language."

Using functional quantization, a tool initially designed to track the stock market, the researchers are creating a "hazard map" that quantifies the probability of Ebola outbreaks at specific locations in a vast geographical area of Africa. Their goal is to help authorities react quickly to Ebola's spread and concentrate available resources where they are most effective. (See story, page 3.)

Data analytics offers new insights into marketing, says Geoffrey Colon '94, communications designer and social data expert at Microsoft.

"We don't make things in a silo anymore and just unleash them on customers," says Colon. "I can look at 50,000 conversations that people have had about Microsoft products, all packed into a sort of spreadsheet. There's humanity behind all that, and we have entirely new ways of going to market with products."

Colon notes that in a recent Fortune list of tech startups valued at over $1 billion, three of the top 10 were founded by people from non-tech fields, such as art and design or social theory.

"Data is crossing into all majors and disciplines—the humanities, political science and product development. Data X is exactly where education needs to move."

In journalism and communication, says department chair Jack Lule, data science is giving the art of storytelling a makeover.

163 %

5-year growth in computer science enrollment

1.4M

new jobs by 2020 in computing and related fields

$30
billion

combined federal research funding in bioengineering, marketing analytics, and digital media

PHOTOGRAPHY BY SATHYA RAM '16

Brian Chen, assistant professor of computer science and engineering (top, right), probes vast quantities of data to study proteins and cells. Lule (above, left) says data analytics is reshaping how journalists tell stories.

"When people think of journalism, they usually think of storytelling with words and photographs," says Lule. "Computer science now provides insights into every aspect of the storytelling chain. It shapes how we find, gather, analyze, present and distribute information. Data X will allow us to explore how journalists can tell stories better with data."

One example of this enhanced storytelling is "Snow Fall: The Avalanche at Tunnel Creek," an article published on the *New York Times* website in 2012. "Snow Fall" weaves text, video, interactive diagrams and photographs together to tell of an ill-fated, backcountry skiing expedition in the Cascades. Graphic elements arise effortlessly for the reader, adding multiple dimensions to the story.

Lule likes to tell students about "mathletes" who bring data-rich insights to reporting. The writer-statistician Nate Silver, for example, used meta-analysis of public polling to predict the winner of every single state in the 2012 presidential election.

"We refer to journalists trained in coding and data as 'unicorns,'" says Lule. "They are rare but they do exist, and they transform newsrooms. We want to produce a generation of unicorns to support the world's newsrooms with Data X."

Michael Spear, assistant professor of computer science and engineering, studies the hardware and software systems that underpin data analytics and make up part of Data X.

"Anytime you see the term 'Big Data,' understand that beneath that you need a very complex hardware and software system to support it," says Spear, whose work in transactional memory employs innovative data management to speed up processing in computing systems.

"What distinguishes the products that change the world," says Spear, "is their software. Their software makes them real-time and interactive. It customizes itself to the way you work and it connects you to the world and leverages all the data that's available.

"The systems that we build are going to need hardware and software that can process data, scale and interact. By learning to build these systems, Lehigh students are going to be able to shape future technology in any field they choose."

Tomorrow's jobs

In almost every conceivable industry sector and discipline, the world is waking up to the power of data—and Lehigh alumni are already leading the way.

Glenn DuPaul, who interned his junior year with Jedlovec, recently became the first director of basketball analytics for the NBA's Brooklyn Nets. Previously, he worked in sabermetrics for the Kansas City Royals.

"The data set we have access to takes a snapshot of the court 25 times per second, and tracks player and ball movement and discrete events like dribbles, passes, shots and screens," says DuPaul.

"My main job is turning raw data into information that can inform objective decisions to assist our staff, including the general manager, coaches, even the strength and conditioning staff. Our process is driven by what question we want to answer."

Brian Davison, associate professor of computer science and engineering, trains his students in large scale data analysis, including recommender and prediction systems, as well as filtering.

"Three of my students recently went to Yahoo! Labs," says Davison, who spent a sabbatical with the data science group at Facebook two years ago. "Others have gone on to become research scientists at Google and Microsoft."

Kathleen Egan '90, vice president with retail-analytics provider Quri, has advanced from the early years of information technology to the onset of the Internet to the latest wave of mobile digital technologies.

"Mobile devices represent another whole wave of data," says Egan, "with geopositioning, people on their devices much more frequently, so many apps open all at once, and personalized information about customers becoming available. What we're seeing now is more sensors, in stores, in people's everyday lives.

"There's a vast ocean of data, and it's getting bigger every day. The trick is to figure out what to do with it."

The interdisciplinary edge

Lehigh's tradition of interdisciplinary education fosters the creativity necessary to use data analytics effectively, says David Griffith, chair of the marketing department in the CBE.

"There's a creativity aspect evolving with Big Data," says Griffith. "You're dealing with unstructured data, and for that you need creative thinkers with a fundamental understanding of what data is and how it can be used by businesses to improve marketing, branding and customer engagement.

"I think that's what we do here at Lehigh. We train people in interdisciplinary ways so that they're able to pull all sorts of ideas together and look at a problem through different lenses."

The university's academic leaders agree.

"Data X reflects and elaborates on what I consider the signature strength of Lehigh—its commitment to interdisciplinary education," said Donald Hall, the Herbert J. and Ann L. Siegel Dean of the College of Arts and Sciences.

"This initiative will allow our students and faculty to explore the exciting synergies between and among their disciplinary homes and the field of data science—where new knowledge is being generated and where jobs are available for students after graduation. I see our college as central to the Data X initiative."

"The integration of a business college of our caliber with a top engineering college is going to place Lehigh in a niche position in the business school world and Lehigh business students head and shoulders above their peers," says Georgette Chapman Phillips, the Kevin and Lisa Clayton Dean of the College of Business and Economics.

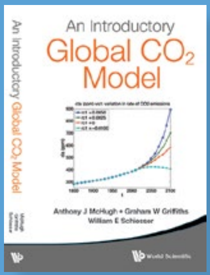
Lopresti sees a thirst for computational and data analytics skills across the board.

"The Data X initiative is very timely now because of massive demand from students in computer science, in engineering and in all other fields—business, humanities, the sciences," he says.

"Employers are crawling over each other to find these kinds of graduates because they see what we see: There's another wave of technological and educational transformation on the horizon. Data X is Lehigh's opportunity to catch this wave."

AN INTERCONNECTED, DYNAMIC PHENOMENON

A new book forecasts rising atmospheric CO_2 levels—even if emissions decline.



USING CALCULUS, PROGRAMMING LANGUAGES, and historic and current data, a new book forecasts that global levels of carbon dioxide will rise over the 21st century even with a worldwide decrease in CO_2 emission rates.

***An Introductory Global CO_2 Model* was published in July by World Scientific Publishing Co. Its authors are Anthony J. McHugh and William E. Schiesser, professors of chemical and biomolecular engineering at Lehigh, and Graham W. Griffiths of City University London.**

The book's model uses ordinary differential equations and the languages Matlab and R to track global CO_2 distribution from 1850 to 2100 in seven "well-mixed reservoirs"—the upper and lower atmosphere, long- and short-lived biota, the upper and lower layers of the ocean, and the marine biosphere.

"Our model output variables are plotted only against time," says Schiesser. "We assume no spatial variation because we view the atmosphere, in regards to CO_2, as a mixed volume. Some countries might emit more CO_2 than others, but everything eventually forms a uniform mixture in the atmosphere."

The authors' model shows atmospheric levels of CO_2 increasing from 280 parts per million in 1850 to 390 ppm in 2008. Assuming four possible trends in future worldwide CO_2 emissions, the model projects 2100 atmospheric CO_2 levels of 900 ppm with a modest increase in emission rates, 700 ppm with a slower increase, 570 ppm with no increase, and 450 ppm with a modest decline.

The authors' model also charts oceanic pH, a measure of acidity, versus time. It shows a worldwide oceanic pH level of 8.25 in 1850 falling to 8.10 by 2015 and to 7.8 by 2100, with acidity, caused by the hydrogen ions in carbonic acid, rising as pH levels drop. The change in pH from 8.25 to 7.8, they say, represents a near tripling of the hydrogen ion concentration in the ocean. The authors project that falling pH will cause a corresponding decline in oceanic levels of calcium carbonate.

"Calcium carbonate," says McHugh, "is what coral reefs and the shells of ocean animals are made of. We show, based on chemistry, that calcium is dissolving as pH goes down."

The capacity of oceans to uptake, or absorb large amounts of CO_2 from the atmosphere, will not offset the increase in atmospheric CO_2, the authors say.

"The oceans are not going to save us," says Schiesser. "Once CO_2 enters the atmosphere, it stays there for centuries even with oceanic uptake."

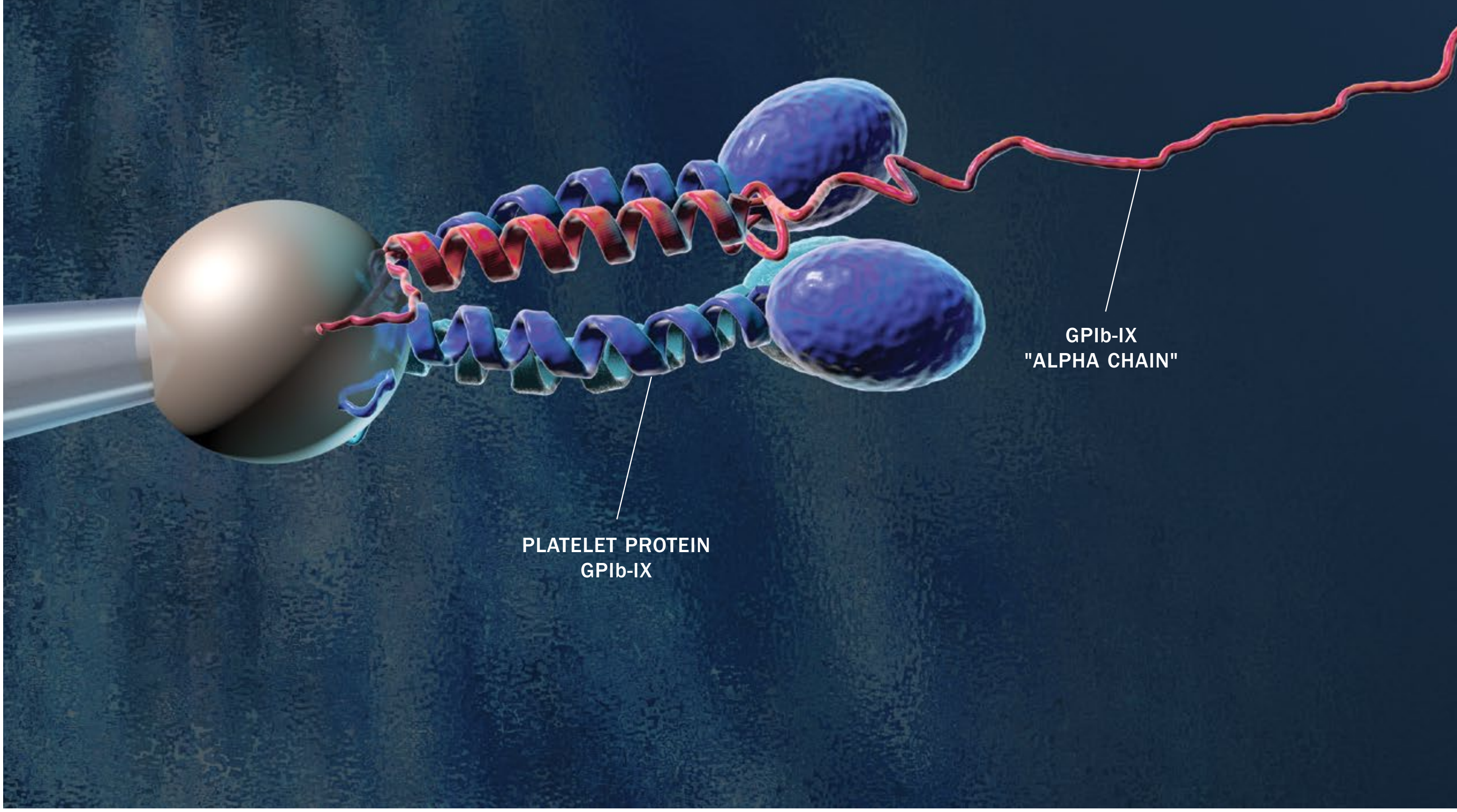
The book contains exercises that allow readers to enter their own variables and play out "what if" scenarios. For example, if CO_2 emissions double, what will oceanic pH be in 2100? Or, what needs to be done for carbonic acid levels to drop to a certain level by 2100?

"Our model shows that the global distribution of CO_2 is an interconnected, dynamic phenomenon in which various reservoirs act like capacitances for carbon," says McHugh. "If you tweak the carbon levels in one reservoir, the others will readjust, but with constants that could take years or even centuries to completely respond."

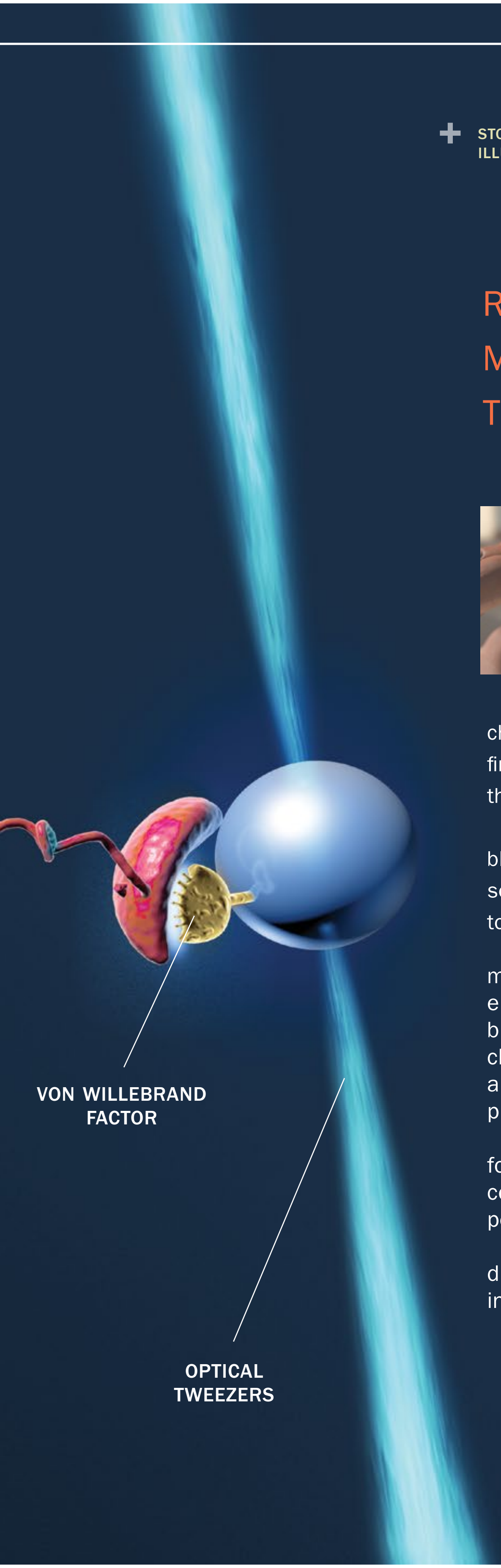
Further information about the book is available at http://www.pdecomp.net.

AN ELABORATE AND VITAL CHOREOGRAPHY

How do platelets sense the shear stress of flowing blood that activates them and instructs them to adhere to injured blood vessels? A group uses optical tweezers to apply the slightest of forces and reveal a complex and interdependent chain of events.



STORY BY KURT PFITZER
ILLUSTRATION BY NICOLLE FULLER



RESEARCHERS ILLUMINATE A MOLECULAR INTERACTION CRITICAL TO BLOOD COAGULATION.

From shaving nicks to paper cuts to lacerations, every rupture of a blood vessel triggers a chain reaction of sensing, signaling, anchoring and clustering as the body's cells and proteins mobilize to form a blood clot.

The actors in this drama, says Frank Zhang, achieve an elaborate choreography enabling platelets—the tiny cell fragments that respond first to a wound site—to form a plug and then a thrombus that seals the wound.

Scientists know what happens at the molecular level to bring about blood clotting, but they have been unable to explain how platelets sense the mechanical force that activates them and instructs them to adhere to injured blood vessels.

Zhang, an assistant professor of mechanical engineering and mechanics, and his colleagues recently shed light on this phenomenon by identifying a critical interaction involving platelets, flowing blood and von Willebrand factor (VWF), the protein that facilitates clotting and prevents unchecked bleeding. They have discovered a "hitherto unidentified mechanosensitive domain" (MSD) in a protein molecule on the surface of the platelets.

The discovery, says Zhang, could have positive implications for the treatment of von Willebrand diseases, a group of genetic coagulation disorders caused by a deficiency or mutation of a person's VWF molecule.

"Our hope is that this will help lead to the development of a drug that will treat or prevent disease," he says, "either by protecting MSD or by preventing the unnecessary activation of platelets."

Zhang and his colleagues, who have received funding from the National Institutes of Health, recently reported their findings in *Blood*, the journal of the American Society of Hematology. Their article was titled "Identification of a juxtamembrane mechanosensitive domain in the platelet mechanosensor glycoprotein Ib-IX complex."

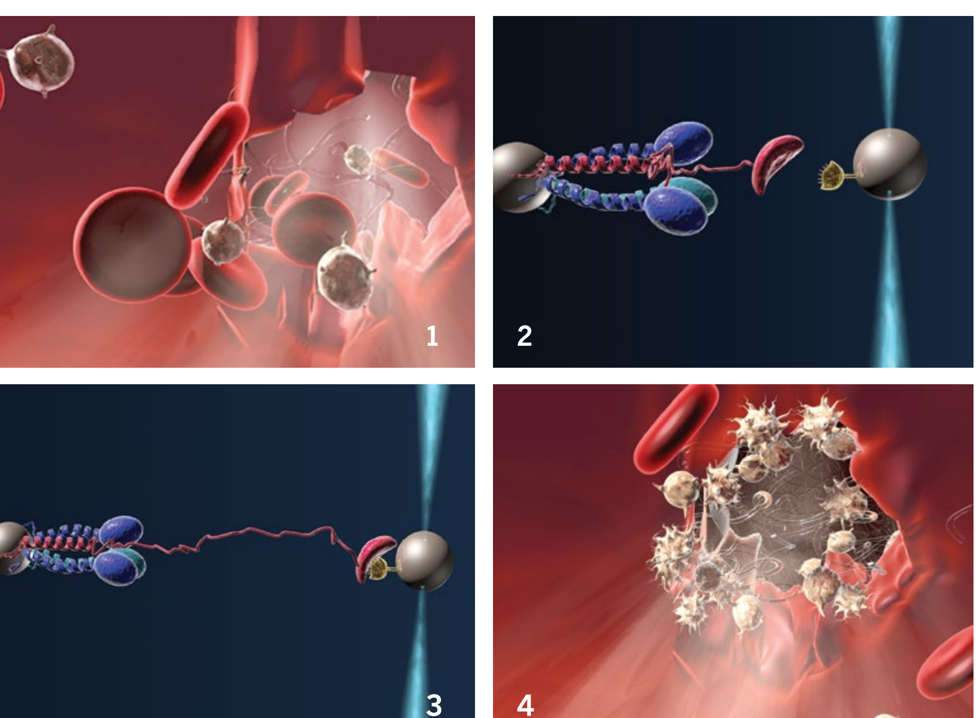
HOW PLATELETS SENSE SHEAR STRESS

The process by which blood coagulates, says Zhang, takes place at multiple levels.

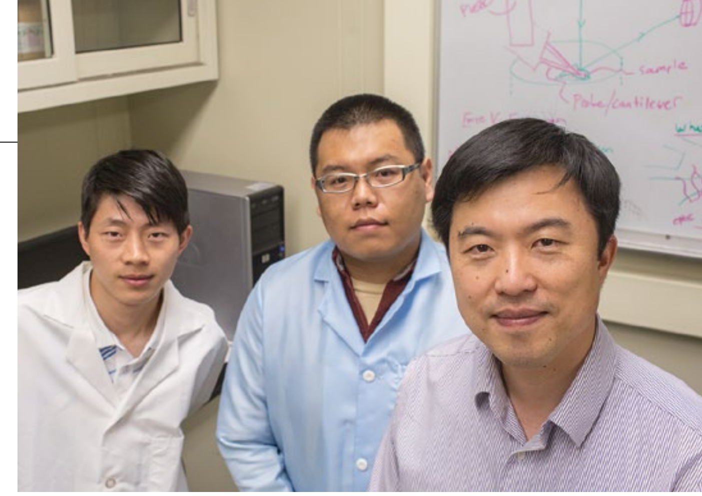
Platelets travel to the site of a wound, but the fast flow of blood makes it difficult for them to bind to the collagen beneath the ruptured layer of endothelial cells. So von Willebrand factor (VWF), a fiber-like protein molecule named for a 20th-century Finnish pediatrician, anchors itself to collagen and then pulls platelets from the blood.

VWF, says Zhang, has 12 domains, including three A domains—A1, A2 and A3—that are essential to platelet adhesion. While A3 binds to collagen, A1 binds to GPIb-IX, a protein molecule on the platelet surface. Scientists have known for 20 years that GPIb-IX acts as a platelet's mechanosensor, sensing the shear, or sideways, stress of flowing blood. Scientists have also learned that the binding of A1 and GPIb-IX causes a platelet to elongate from a sphere into a flatter particle, to extrude filopedia that stick to the collagen, and to stack on top of other platelets to form a plug.

VIEW THE VIDEO @ **bit.ly/luzhang**



Platelets (1) bind to collagen and VWF, while optical tweezers (2, right) immobilize VWF (near right) and GPIb-IX (left). GPIb-IX (3) is unfolded by VWF, signaling more platelets to gather and (4) form a clot.



Wei Zhang, Yan Xu and Frank Zhang (l-r) have taken the first single-molecule force measurement of the protein molecule on the platelet surface that binds to a second protein that anchors itself to the collagen at a wound site.

Until now, however, no one has explained how a platelet senses the shear stress and how it interprets and acts on this information, Zhang's group wrote in their article in the journal *Blood*.

"How this [GPIb-IX] receptor complex senses shear stress and converts this mechanical information into a protein-mediated signal that can be recognized and propagated [by the platelets] has remained elusive," the group wrote.

Zhang and his students explore this phenomenon using optical tweezers. By focusing a laser with a large light spot into a tiny area, they concentrate its intensity and enable it to pin and immobilize beads, or spheres, that measure 2 microns in diameter.

"We immobilize VWF on one sphere and GPIb-IX on another," says Zhang. "We bring the two spheres together and watch the two molecules interact.

"We use an optical fiber with a nanopositioner to move the bead. We move the trap slowly to the left and the force slowly increases. We can sense the position of the sphere and measure the force. The distance that the sphere moves from the trap in the center is proportional to the force that we apply.

"We do this with a one-nanometer precision; we apply only tens of piconewtons of force."

In this manner, says Zhang, his group has determined that the GPIb-IX receptor extends in an "alpha chain" from the platelet membrane and that the end of this chain binds to VWF-A1. The force of the flowing blood tugs on this chain and causes a portion of the chain—the "hither-to unknown" MSD—to unfold, stretch away from the VWF and disrupt the structure. As it unfolds, the MSD sends a signal to activate the platelet.

"The end of the MSD stretches away from the VWF as blood flows past," says Zhang, "very much like a ship's anchor, which stretches or pulls away from the ocean floor in response to the force of the ocean waves.

"During this stretching, the MSD, which is a protein with a 3D amino acid structure, unfolds until the structure is disrupted."

Using the optical tweezers, Zhang's group was able to identify the threshold force necessary to disrupt the MSD. They attached one sphere to the platelet and one to the VWF and pulled the two spheres apart very slowly, gradually increasing the force until the elastic structure (the MSD) suddenly popped apart into its unfolded phase.

"In our optical tweezer experiment we have observed the binding and unbinding of VWF-A1 and full-length GPIb-IX at the single-molecule level," the group wrote in its article. The researchers added that they were the first to take a "single-molecule force measurement of the full-length GPIb-IX complex."

Its results, the group wrote, "suggest that VWF-mediated pulling under fluid shear induces unfolding of the mechanosensitive domain in GPIb-IX, which may possibly contribute to platelet mechanosensing and/or shear resistance of VWF-platelet interaction."

Zhang's group plans to study platelet activation and VWF diseases in greater detail.

The current project is a collaboration involving researchers from Lehigh, the Aflac Cancer and Blood Disorders Center of the Emory University School of Medicine, the University of Texas Health Science Center at Houston, and the Puget Sound Blood Center in Seattle.

The lead author of the *Blood* article is Wei Zhang, a Ph.D. candidate at Lehigh. The other Lehigh authors are Frank Zhang; Yan Xu, a Ph.D. candidate; and Yizhen Wang, a former postdoctoral researcher who is now an associate professor of physics at the University of Hainan.

The Emory authors are Renhao Li, an associate professor in the university's School of Medicine who has studied the molecular structure of GPIb-IX for 12 years; Wei Deng and Xin Liang, postdoctoral research fellows; and Liang Zhou, a senior research scientist. The remaining authors are Wenjun Yang of the University of Texas Health Science Center and John D. Kulman of the Puget Sound Blood Center.

DETECTING DISEASE, ONE WHITE BLOOD CELL AT A TIME

When white blood cells, the building blocks of the human immune system, encounter viruses or harmful bacteria, they secrete molecules to summon more white cells to the site.

Researchers typically use an enzyme-linked immunosorbent assay to determine how many molecules white cells secrete to rally other cells. A sample indicates the presence of antigens, which cause the immune system to produce antibodies. However, this method yields no clues about white cells' behavior over time against intruders.

Knowing how immune cells respond to attackers in real time could help researchers learn how cells regulate each other's functions. Some immune cells are early responders, while others join the battle later. The information could also enable labs to get results—and help diagnose infections or diseases—more quickly.

"These interactions are not well understood, because they involve very complicated communication among cells," says Xuanhong Cheng, associate professor of materials science and engineering. "We lack the tools to study a time response of how immune cells' secretions modulate their responses. This could have diagnostic implications."

Cheng is working with Filbert Bartoli, the Chandler Weaver Chair of Electrical and Computer Engineering, to monitor white blood cell function using a novel, handheld nanoplasmonic sensor device. The project is supported by NSF.

"Our approach uses interferometers, which combine two light signals traveling along different paths," says Bartoli. "When they meet, we see an oscillatory pattern. We are combining this very sensitive technique with plasmonic technology to increase performance.

"If you attach biomolecules to the sensor surface, it causes a phase shift in the interference pattern of oscillations between the two beams. This shift can be used to detect biomolecules."

The researchers coat the surface of the sensor with a substance that recognizes cellular secretions. When the antigen-indicating secretions of the white blood cells bind to the coating on the sensor, they generate a local optical property change.

In a November 2014 paper in *Nanoscale*, Bartoli and his students showed that their circular plasmonic interferometer can distinguish between the binding of biomolecules on the sensor surface and changes in the index of refraction of the volume of fluid above the sensor surface.

Cheng and Bartoli plan to build a multiplexed array of individual sensors that can sense different biomolecules at the same time. First, they must perfect a single sensor and integrate it with a cell culture. The cell must be placed close enough to the sensor surface so the molecules it generates can be captured before they diffuse away, Cheng says.

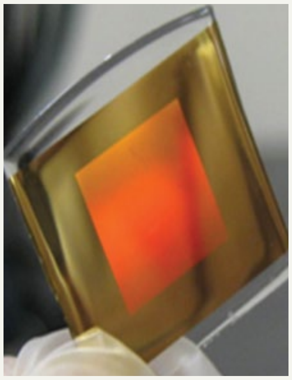
"Each sensor has to be very sensitive and compatible to the size of a single white blood cell, which is 10 microns in diameter," says Cheng.

Cheng and Bartoli have previously used a biosensor to detect bovine serum albumen and its antibody. "We were able to measure 0.4 picograms per square millimeter of antibody," says Bartoli. "Commercial instruments don't do much better. Our method presents the opportunity for much better multiplex sensing, and it's less expensive because you can shine light and look at the results with an optical microscope."

The two researchers believe their nanoplasmonic sensor device will provide a snapshot of the immune system in action and track disease progression by giving a glimpse at how white blood cells respond to antigens.

Bartoli, who directs the Biophotonics and Optoelectronics Lab, is designing the sensor. Cheng, who studies microfluidics, is integrating it with cell culture. Preliminary data measured cellular response using sensing platforms and groups of white blood cells. However, a heterogeneous response from a group of cells provides only an average response about how much molecule a cell secreted.

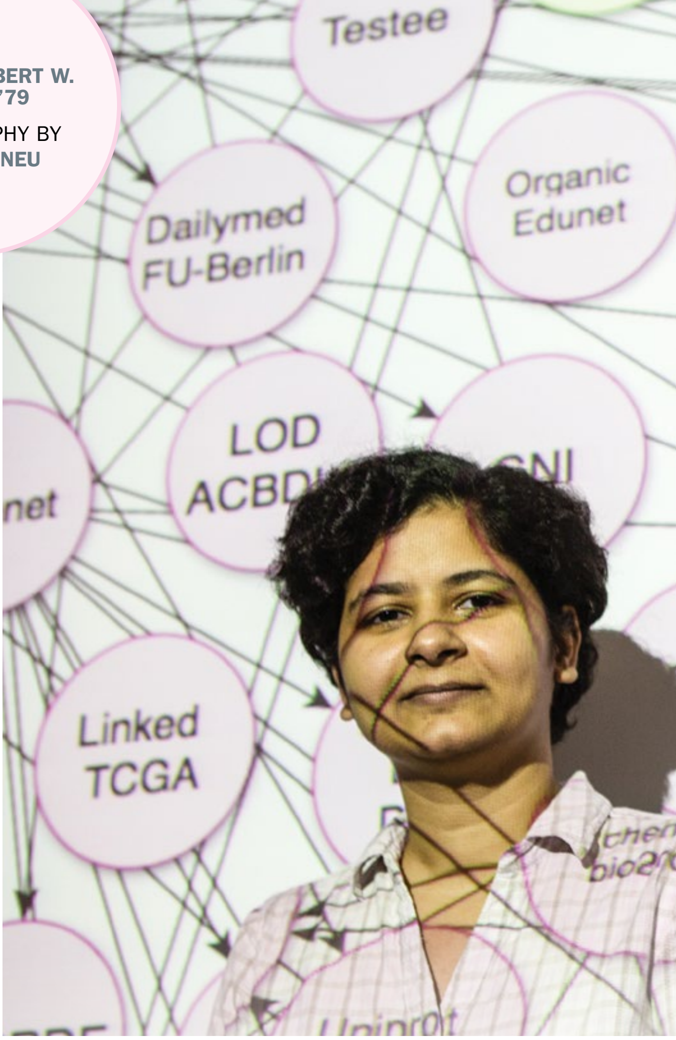
"Detecting the response of a single cell gives us information that leads to effective diagnosis for tuberculosis and other infectious diseases," says Cheng, "because the number of cell responses to the tuberculosis antigen determines whether someone has an active or latent infection." That difference, she adds, can be crucial when choosing a treatment.



Each sensor in Cheng and Bartoli's multiplexed array will be compatible to the size of a single white blood cell.

STORY BY ROBERT W. FISHER '79

PHOTOGRAPHY BY CHRISTA NEU



A question, *quickly*, of semantics

A SWAT TEAM DRAWS POWER RAPIDLY AND ACCURATELY FROM A SUBSET OF THE INTERNET.

Imagine getting good Internet search results from an imprecise query like "What are the trends in Pennsylvania's economy?" Or empowering a software agent to scour multiple airline databases and decide the best flight based on your preferences—and suggest things you might like to do at your destination.

That is the potential of the semantic web, a subset of the web that has been augmented to allow computers to make implicit connections between data.

"The semantic web synthesizes information from across the web to bring more power to us," says Jeff Heflin, associate professor of computer science and engineering.

Heflin has been "working in this field as long as it has been a field." He investigated knowledge representation on the web as a graduate student at the University of Maryland in the late 1990s, before the seminal Scientific American article by Sir Tim Berners-Lee and others introduced the field to the wider world in 2001.

The nearly one billion sites on the World Wide Web are created with hypertext markup language (HTML), which specifies the layout and style of web pages. Search engines like Google and Yahoo look for keywords in the text and generate good matches if you have queried for the right terms. But, Heflin asks, "What do we do if we don't know how to phrase the question precisely?"

The semantic web will help bridge that gap. Code written to understand data formats can search and find relationships between facts in publicly accessible databases that don't show up in web searches. Governments, research agencies and corporations have made some 60 billion "facts" available on the web, Heflin says, and the number is growing. There is also commerce and personal data from websites, merchants and social media sites that isn't free but may be sold for others to analyze.

Languages such as Resource Description Framework (RDF) and Web Ontology Language (OWL) represent data in graphs—bits of information linked by specific relationships. For example, John's personal site URL might be linked by a property "last name" to a field of data "Doe," or by "gender" to "male." Software can traverse the links between many databases to reason that "Jane" is his "sister" or "Lehigh" is his "employer."

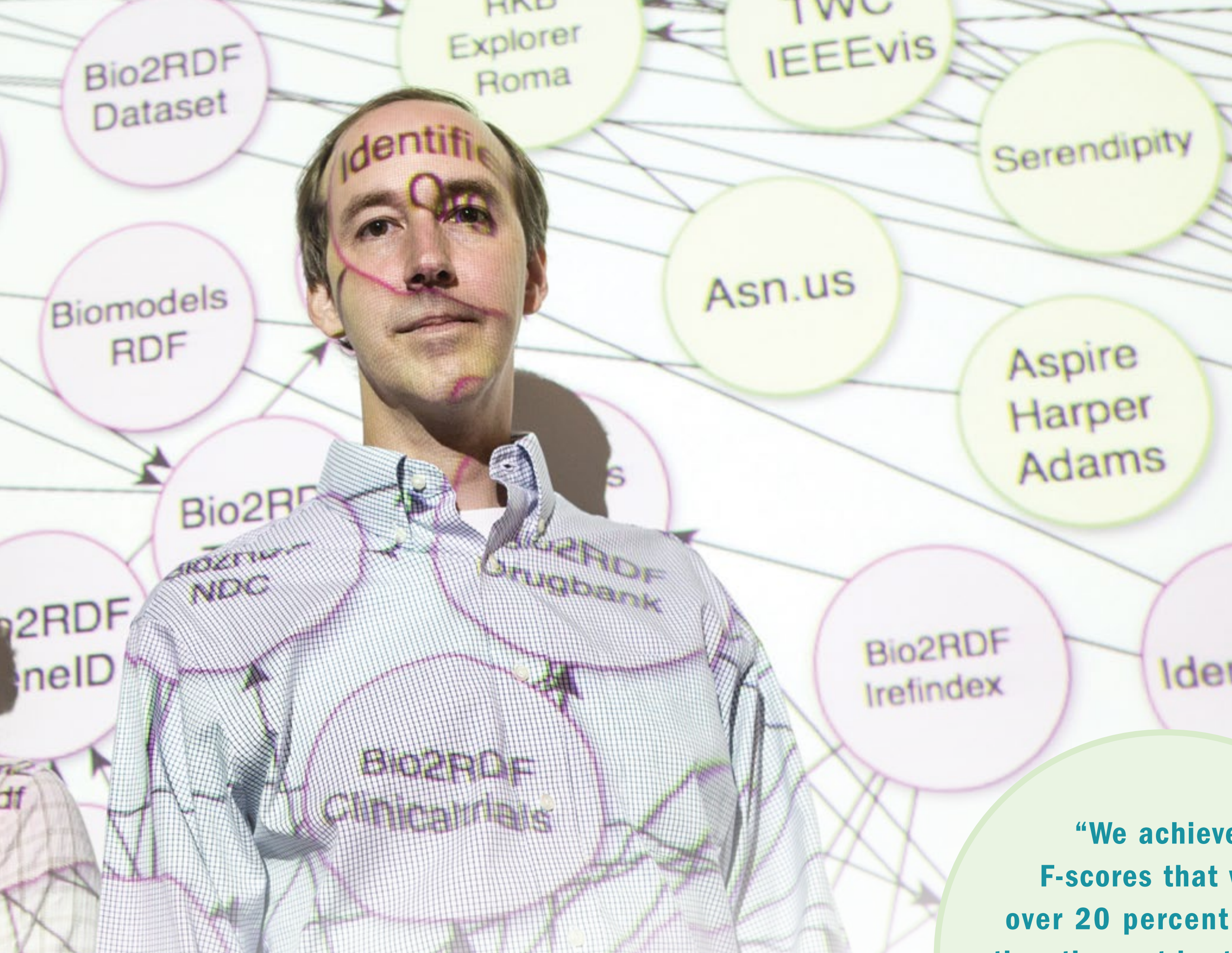
With tens of thousands of bits of data on the web for any individual or entity, finding the needle in this haystack is a lengthy, computing-intensive process. Heflin and his team at the Semantic Web and Agent Technologies (SWAT) Lab are developing algorithms and code that can make connections rapidly and accurately.

The researchers scale algorithms and code to work quickly across large data sets. Automatically determining matches between identifiers in different databases is another area of interest. And they design interfaces that allow ordinary users to effectively search the semantic web.

The semantic web's parent, artificial intelligence, uses very small data sets of a few thousand items, Heflin says. "I want to do accurate searches at the scale of billions of items. I focus on techniques that take a very large subset of the web and rapidly find matches among identifiers."

Success in this field is measured by precision (how many of the data links that you find are on topic?) and recall (how many of the links on a given topic do you find?).

"There are two ways you can be wrong," Heflin says. Finding one accurate match is precise but shows low recall.



Graduate student Sambhaya Priya (left) helps Heflin write algorithms and code that make rapid, accurate connections among bits of data.

Lehigh is hosting the 2015 INTERNATIONAL SEMANTIC WEB CONFERENCE in October in Bethlehem, Pennsylvania. **See story, page 12.**

Returning a broad swath of links may have high recall but is imprecise. The trick is finding the sweet spot.

Data on the semantic web can be represented in graphs that display the links between information. In the case of John Doe, his web address and “Doe” can be seen as two ovals, linked by a line representing the property “last name.” A single record in a database can have many properties.

To help make this web of data more useful, Heflin’s team focuses on scalability—quickly filtering out data properties that do not match.

To find “high co-occurrence” between the values that populate these properties, Heflin compares graphs about the individuals in question. (A key contributor to this effort, Dezhao Song ’13 Ph.D., is now with Thompson Reuters.) First name fields have many recurring values. Zip codes and Social Security numbers have common properties as number strings of certain sizes.

With billions of pieces of data across the semantic web, finding links can require making a billion billion comparisons, eating up time and computing resources. Heflin leverages a search engine concept known as an “inverted index”—a list of all the values for a given property—to quickly filter out data pairs that are not likely to match. No other research teams, he says, have tried this technique of instance matching “at such a large scale.”

“We achieved F-scores that were over 20 percent better than the next best system, and we did it 10 times more quickly.”

—Jeff Heflin

By looking for strings that are comparable in size or have a lot of shared information, the technique also has the benefit of being domain independent. “It does not require any specialized knowledge about the data topic to work,” Heflin says.

The SWAT system’s scalability and improved candidate matching get world-class results.

Each year researchers compare their algorithms through the Ontology Alignment Evaluation Initiative (OAEI). Performance of semantic web software is measured in F-scores, which combine ratings of the code’s precision and recall. Heflin’s team has not entered, but it has compared its systems to the top contenders and other published results.

“Our software was twice to an order of magnitude better than other systems,” he says. “We were getting comparable or better accuracy, with significantly faster times. Using a data set of 50,000 item descriptions drawn from real world Linked Data, we achieved F-scores that were over 20 percent better than the next best system, and we did it 10 times more quickly. This data set includes a diverse array of items—people, places, books, products, chemicals, proteins and more.”

STORY BY **ROBERT W. FISHER '79**

A PLATFORM TO LAUNCH THE "NEXT BIG THING"

CSB IS PROVING ITS VALUE TO A GROWING NUMBER OF YOUNG ENTREPRENEURS.

In his job with the investment banking wing of UBS Financial Services, Alex Price '14 wears the hats of emergency responder, forensic investigator and translator. His team monitors trades for problems, probes error files for fixes, explains situations to frustrated traders, and works with software developers to patch bugs.

"We are the firefighters of Wall Street," Price says.

Price learned to speak the languages of computer scientists and business leaders in Lehigh's Computer Science and Business program. CSB, the only program of its kind accredited in both disciplines, teaches students how technology interfaces with all areas of business.

"CSB is for students who want to make technology happen, not just cope with it," says program co-director Hank Korth, the Weisman Professor of Computer Science and Engineering. "We're giving them the tools to master the next big thing to come along—or create it."

> "CSB is for students who want to make technology happen, not just cope with it."
>
> —Hank Korth

"There is no other program like CSB in the country," says its co-founder, James A. Hall, the Peter E. Bennett '63 Chair in Business and Economics.

CSB was launched in 2000 with help from Bennett, chairman of New York private equity firm Liberty Partners, who provided a $2.4 million grant. The tech bubble was collapsing and computer science enrollments were down, but Hall and others saw a need for integrated education.

"It was really obvious to me that many IT people didn't have a clue about business concerns, and many business people abdicated any responsibility for technology," says Hall, a former systems analyst. "There was a need [for a program like CSB] for decades, but it had never been satisfied because universities are structured with silos in business and engineering.

"At Lehigh, we don't have silos. This kind of interdisciplinary program is our niche."

The decision to create CSB was prescient. In 2002, Congress passed the Sarbanes-Oxley Act in reaction to corporate accounting scandals. Sarbox required top management to personally certify financial controls and results and, says Hall, "created a great demand for people with deep skills in business and technology."

CSB began with 11 transfer students. Twenty freshmen entered in 2002 and by 2014, there were 173 majors. The class of 2019 has a bumper crop of 57 freshmen selected from 368 applications.

In addition to rigorous coursework, CSB requires students to complete a two-semester senior capstone project in which they work with a business or IT company to solve real-world problems.

CSB grads are highly sought by major financial services and consulting firms and by tech giants such as Google and Microsoft. The Class of 2014's CSB graduates averaged a mean starting salary of $81,750, compared to $70,262 for computer science grads and $60,200 for business information systems majors.

CSB alumni see a natural fit between the program's two disciplines.

"There is a symbiotic relationship between computer science, which is heavily mathematical and logical, and

1ST CSB DEGREE
2005

TOTAL CSB ALUMS
190

MEAN STARTING SALARY
81.7K

POST-GRAD PLACEMENT
99.3%

PHOTOGRAPHY BY BILLY COLE/ORANGE PHOTOGRAPHY

Thanks to CSB's rigorous coursework and unique accreditation, its graduates, like Spencer Johnson '13, are highly sought by major companies.

business, which depends on rules and logic but is much more about relationships with customers, colleagues and competitors," says Spencer Johnson '13, who now helps Google fight click-fraud while ensuring that users see relevant ads.

"CSB combines two fields that, in my opinion, are inseparable," says Basilio Garcia Castillo, a junior from Spain. "I have been interested in computer science since I was a kid. However, I also like working with people, organizing events and understanding the environment that I am working or studying in."

Wellesley "Wes" Arreza '16 is working with a team to develop a web application for the advisers and clients of a $600-billion wealth management firm. CSB, he says, "gives you the opportunity to network with employers and get hands-on learning in industry technologies.

"In today's industry, knowing theoretical computer science and a couple of APIs is not enough. To create valuable software, you have to think about the business side."

"CSB gives you the best of both worlds," says Alex Ratner '14, who worked with classmate Tyler Costantino '14 (a management major) to develop Rally, an app that connects friends and their nightlife experiences.

"Facebook and Twitter become almost irrelevant after 6 p.m.," says Ratner. "Rally is the first-ever social 'nightwork.'" Rather than posting publicly on the big networks, young adults share photos and text each other to plan a night on the town. The app switches on at 6 p.m., allowing users to snap pictures to an Instagram-like feed and access a GPS-tracked map of their night.

"If you want to build your own thing, CSB gives you an excellent background," Ratner says. Programming experience enabled him to wireframe and mock up the iOS app. "And I am not going to be randomly hiring developers I think are good. I can read and test their code myself."

In March, Rally was one of 50 companies out of thousands that were chosen to present—live—before 10,000 people at the 2015 LaunchFestival. "It was awesome, and reassuring," says Ratner, "to be selected as one of those companies.

"We want to be the name people think of when they think of the night," Ratner says. He quit a safe corporate job to start up Rally, but his CSB degree made the move a risk worth taking.

"If this doesn't work out," he says, "I feel like I could get another job in a week."

Banerjee and his students investigate Rayleigh-Taylor instabilities, which hamper efforts to create fusion energy on an industrial scale.

Obtaining energy from fusion

The first job Arindam Banerjee took after graduating from Jadavpur University in Calcutta was with Tata Motors, one of India's largest automobile manufacturers.

It changed the course of his life.

Banerjee was one of a small group of engineers chosen by Tata to receive Six Sigma quality management training. Soon the skills were being rolled out company-wide. One afternoon, the Six Sigma instructor was not available and Banerjee was tapped to teach the session.

"I was called in with 15 minutes' notice to teach a room full of senior executives," Banerjee recalls. "I had never been as comfortable doing something as what I experienced in the next four hours. I quickly realized there were not enough challenges the company could offer me with my limited knowledge."

Banerjee, son of a University of Calcutta professor, knew teaching was in his blood. He earned a Ph.D. at Texas A&M, did a postdoc at Los Alamos National Laboratory in New Mexico, and taught at the University of Missouri-Rolla before arriving on South Mountain in 2012.

Today, as P.C. Rossin Assistant Professor of Mechanical Engineering and Mechanics, Banerjee is gaining renown in the field of fluid dynamics. Last spring he received the NSF CAREER Award to study the physics of mixing molten metal plasma and hydrogen gas in the fusion process.

Banerjee, who leads a group of seven graduate students and several undergraduates, exemplifies the teacher-scholar model that NSF promotes. He recently received the Joel and Ruth Spira Excellence Award in Teaching from the engineering college.

"All great researchers," he says, "are great teachers. If you do not have a passion for discovering new things, you will not have a real passion to teach."

In his research, Banerjee studies Rayleigh-Taylor instabilities, which hamper efforts to create fusion energy on an industrial scale.

Fusion, the process by which the sun creates energy, "has been the next big thing for about 30 years," Banerjee quips. He conducts experiments to simulate the mixing that occurs when metal spheres filled with hydrogen are irradiated by lasers to trigger fusion. However, surface imperfections on the metal surface give rise to hydrodynamic (Rayleigh-Taylor) instabilities that allow the gas to escape through the metal.

"It's a timing issue," says Banerjee. "The instabilities do not allow the time it takes to attain fusion burn by rupturing the metal shell due to the mixing process."

Banerjee and his students use a pair of rotating cylinders containing a test section full of materials that simulate the densities of gas and molten metal at high speed, then reverse gravity to cause mixing. Lasers and fast cameras capture a detailed view of the flow.

"We use a large number of fluid combinations to explore hydrodynamic conditions that may be prevalent at extreme temperatures and pressures," he says. "One particularly interesting combination is Hellmann's Real Mayonnaise. It turns out that it has very similar elastic-plastic [non-Newtonian] properties as plasma does at high temperature and pressure."

The results of these experiments, which are also supported by the Department of Energy, can shed light on the complex hydrodynamics and mixing processes for inertial fusion. The results also feed into research at the Los Alamos and Livermore National Laboratories that collect data to model the mixing, nuclear, heat transfer and other processes that affect fusion.

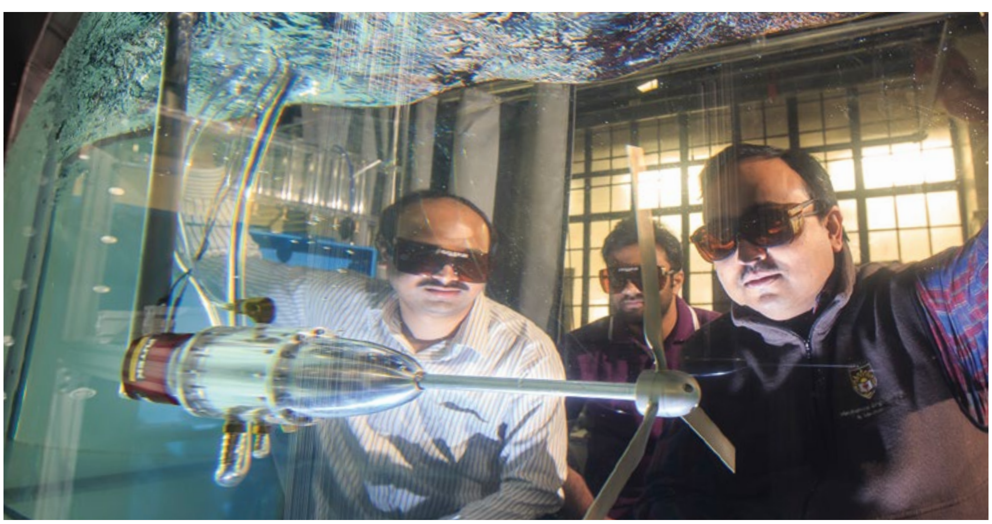
Banerjee is also interested in harvesting renewable hydrokinetic energy from rivers, tides and ocean waves. He uses a large flow channel to understand the challenges of this potentially huge energy source.

"The U.S. could harvest enough energy from rivers and tides, at 30 percent efficiency, to meet one-third of its electricity demand by 2030," he says. A number of demonstration turbines have been deployed, he says, but hydrokinetics has so far contributed little energy to the grid.

Because the impacts of turbines on U.S. rivers and coasts aren't well known, it can take three to five years to obtain the permits necessary to put a turbine in service. By studying flow effects in the lab and computationally modeling real-world conditions, Banerjee's work could help smooth public acceptance of this technology.

Students play a large role in his projects, says Banerjee, because he believes "it's important for them to get into the lab and get their hands dirty.

"In the lab, there is always in the beginning a fear of the unknown, because there are no fixed answers to experimental problems. But as they start realizing that they have the freedom to approach it however they want to, I see them flourish."



"All great researchers are great teachers. If you do not have a passion for discovering new things, you will not have a real passion to teach." —Arindam Banerjee

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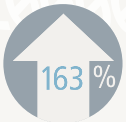

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163% increase in computer science course enrollment over 5 years

24:1 student-to-faculty ratio in computer science classes

10:1 student-to-faculty ratio at Lehigh overall

STRONG DEMAND FROM EMPLOYERS

1.4 million new jobs in computing by the year 2020

Only 400,000 graduates to fill them

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A LIVING LAB FOR THE INTERNET OF EVERYTHING

As Philadelphia's first Chief Technology Officer, triple alumnus Allan Frank '76 '78G '79G created a multifaceted program to expand access to data and thereby improve government efficiency, public safety and economic prosperity.

See page 8