WITH CONTROL COMES HOPE

Brain-computer link factors in feedback to restore function to the impaired.

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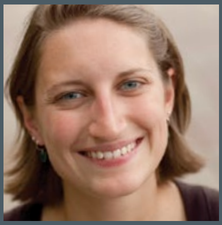

STUDENTS SEIZE THEIR FUTURE

Undergraduate research contest kindles interest, sharpens skills.

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ON THE COVER

A computer-generated map shows the relationships of sites on the Internet, one well-known application of high-performance computing.

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The computational third pillar

Welcome to* Resolve*, a magazine devoted to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh.

As this issue of *Resolve* goes to press, Lehigh is gearing up for a two-day workshop titled "Computational Engineering & Science/HPC: Enabling New Discoveries." The event's participants will explore the pressing needs and opportunities associated with cutting-edge research endeavors that are computational in nature – and those that depend upon high-performance computing (HPC) resources for success.

Advanced computing, along with theoretical exploration and laboratory experimentation, constitutes a "third pillar" of scientific inquiry. In the past 20 years, computing has played a leading role in major scientific and technological breakthroughs that are critical for sustained scientific leadership and economic competitiveness. Computing allows researchers to map the human genome, project climate change and ecological impact, and simulate such complex phenomena as protein folding and nuclear fusion. Computing and computational research are now an integral part of scientific discovery.

Continued advancement in computing is critical for us to meet the grand challenges of our time – in health care, in energy and the environment, in infrastructure renewal, and in global economic development. Our Fall 2009 workshop will bring together researchers who explore high-end computational technology and methodologies, and researchers from all areas of science and engineering who rely increasingly on HPC platforms for their research. This kind of interaction will lead to new perspectives and new opportunities for discovery.

In this issue of *Resolve*, we highlight the activities of Lehigh researchers who use HPC resources and expertise to solve complex problems. These endeavors have very different expected outcomes, but they share two features: big-time computing needs and tremendous potential impact.

Lehigh researchers use computational modeling to help doctors improve cancer-radiation techniques to limit damage to healthy cells around tumors, or to allow people stricken with immobilizing diseases to control devices through "thought recognition." Others seek to gauge the effect of earthquakes on interconnected infrastructure systems, or to understand the diffusion of aluminum and oxygen ions in the manufacture of advanced ceramics. Still others intend to improve the effectiveness of search engines on the Web.

"Advances in computing are critical for us to meet the challenges in health care, energy, infrastructure and the global economy." – S. David Wu

These diverse research activities in the College translate quite readily into our classrooms and undergraduate labs, as evidenced in the article about Lehigh Engineering's annual research competition, the David and Lorraine Freed Undergraduate Research Symposium. The symposium grows in stature each year, the competition is sharper than ever, and the research involved is increasing in sophistication. This past year, the symposium expanded to include engineering students from our archrival Lafayette, ratcheting up the competitive spirit even further. The symposium, made possible by a generous endowment from an alumnus, is enhancing the Lehigh experience for many of our students, and its positive impact on our students is palpable.

I hope you enjoy this issue of *Resolve*. Please drop me a note to share your thoughts and comments.

S. David Wu, *Dean and Iacocca Professor*
P.C. Rossin College of Engineering and Applied Science
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Tapping the potential of biomass

The world has spent billions to develop ethanol fuel additives, says Mark Snyder, but relatively little to make hydrocarbon fuels directly from biomass, which could potentially provide nearly half of America's energy.

Snyder uses titania for selective biomass catalysis in the liquid phase.

Snyder, the P.C. Rossin Assistant Professor of chemical engineering, is seeking to convert biomass more efficiently into chemicals and fuels. He collaborates with researchers from six other universities and one national lab in a project funded by a DOE Energy Frontier Research Center (EFRC) at the University of Delaware.

Ethanol additives are derived primarily by fermenting sugars produced from corn. Snyder wants to convert woody residues that are mostly waste products into fuels that are chemically no different from gasoline. Auto engines would not distinguish biomass-derived fuel from regular unleaded, nor would refineries need significant retrofitting. The chemicals produced from biomass could be used in textiles, food packaging, cleaners, plastics, dyes, clothing and cosmetics.

Snyder is developing new, hydrothermally stable titania materials whose pore structure and customized catalytic surface hold promise for liquid-phase biomass catalysis. In this type of catalysis, sugary biomass molecules derived from the breakdown of woody materials are reacted in water at moderate temperatures. The process has advantages over high-temperature gas-phase reactions. It uses less energy, it can process sugar molecules that are unstable at high temperatures, and it can tune solution conditions like pH to control reactions.

Porous titania has been explored for other catalytic applications, but Snyder is the first to use titania to achieve efficient and selective biomass catalysis in the liquid phase. Conventional catalysts used in petroleum and petrochemical refining are unstable under liquid-phase conditions. The challenge in designing new catalysts is to tailor pore size, connectivity and surface function to control how biomass molecules access catalytic sites and how they are transformed into fuels or chemicals.

"The overall biomass-to-liquid-fuels process is essentially carbon-neutral," says Snyder. "The natural process of photosynthesis during the regrowth of new woody biomass effectively cleans from the atmosphere any CO_2 produced during the burning of biomass-derived fuels."

"Liquid phase biomass conversion has a way to go," says Snyder. "It's very promising, but how much it contributes will depend on its level of development."

Of cellular interiors and micromechanics

Alberto Bilenca and Jeetain Mittal, two new professors in different engineering disciplines, converge in their interest in biological challenges.

Bilenca, assistant professor of electrical and computer engineering, works in biomedical photonics. He is studying imaging and sensing of the nanoworld in biocompatible settings, which could close the resolution gap between electron and conventional optical microscopy, and revolutionize the way we understand biology.

He works with ultrasensitive microscopy to target cavity-controlled light-based cytomics and proteomics. "This is a unique microscopy technology that is particularly important in cellular nanomechanics and single molecule experiments, where the detected optical signals are extremely low in power," says Bilenca. "It also has the capacity to impact applications such as biomechanical imaging and lab-on-a-chip-based molecular recognition."

Bilenca also uses light microscopy to quantitatively identify and classify tissue and biomaterials, which is essential to biomedical research. "I am investigating the use of optical coherent and scattering effects in disordered media to offer inexpensive, point-of-care technologies for tumor and blood disease diagnosis."

Bilenca uses ultrasensitive microscopy to classify biomaterials.

Mittal is fascinated by the interior of a cell, which he says is a concentrated soup of several macromolecules. "I focus on macromolecular crowding effects, where the cell constituents not actively participating in a given reaction under study are labeled as part of the crowd." He notes that the presence of a large number of macromolecules will change the behavior of the most important constituent in the cell – water – which modulates reactions in the cell.

He uses a "divide and conquer approach" to understand macromolecular crowding effects. "We construct theoretical models with different degrees of complexity. For example, we will build models that separate the direct effect of crowding from the indirect effect through hydrophobic interactions in order to break the problem into manageable subsets."

Advanced computational methods generate data on long-time behavior, Mittal says, which can be used to predict the collective behavior arising from various effects closely resembling the interior of a cell. This will help extend the findings from commonly performed dilute solution experiments to solution conditions resembling intracellular environment.

Mittal (above) and Bilenca apply engineering to biology.

DNA brings carbon nanotubes' promise closer to reality

A DuPont-Lehigh team, using tailored sequences of DNA, reports breakthrough in the campaign to sort and separate CNTs.

A team of researchers from DuPont and Lehigh has reported a breakthrough in the quest to produce carbon nanotubes (CNTs) that are suitable for use in electronics, medicine and other applications.

In an article published in the July 9 issue of *Nature*, the group says it has developed a DNA-based method that sorts and separates specific types of CNTs from a mixture.

A focus on chirality

CNTs are long, narrow cylinders of graphite with a broad range of electronic, thermal and structural properties that vary according to the tubes' shape and structure. This versatility gives CNTs great promise in electronics, lasers, sensors and biomedicine, and as strengthening elements in composite materials.

Current methods of producing CNTs yield mixtures of tubes with different diameters and symmetry, or "chirality." Before the tubes can be used, however, they must be disentangled from a mixture and "purified" into separate species of CNTs of the same electronic type.

"A systematic method of purifying every single-chirality species of the same electronic type from a synthetic mixture of single-walled nanotubes is highly desirable," the DuPont-Lehigh group wrote in *Nature*, "but the task has proven to be insurmountable to date."

The *Nature* article is titled "DNA sequence motifs for structure-specific recognition and separation of carbon nanotubes." Its authors are Ming Zheng, Xiaomin Tu, Anand Jagota and Suresh Manohar. Zheng and Tu are scientists with DuPont Central Research and Development. Jagota is a professor of chemical engineering at Lehigh. Manohar is a graduate student in chemical engineering at Lehigh.

In 2003, a different team of scientists from DuPont, MIT and the University of Illinois at Urbana-Champaign developed a new method of separating metallic CNTs from semiconducting CNTs using single-stranded DNA and anion-exchange chromatography. The scientists reported their discovery in *Science*.

The new results expand the 2003 results by identifying more than 20 DNA short sequences that can recognize individual types, or species, of CNTs and purify them from a mixture.

The new method, according to the researchers, utilizes tailored DNA sequences and "allows the purification of all 12 major single-chirality semiconducting species from a synthetic mixture, with sufficient yield for both fundamental studies and application development."

A big, open field

The current experiments were conducted by Tu and Zheng, while Manohar and Jagota developed structural models using molecular simulations.

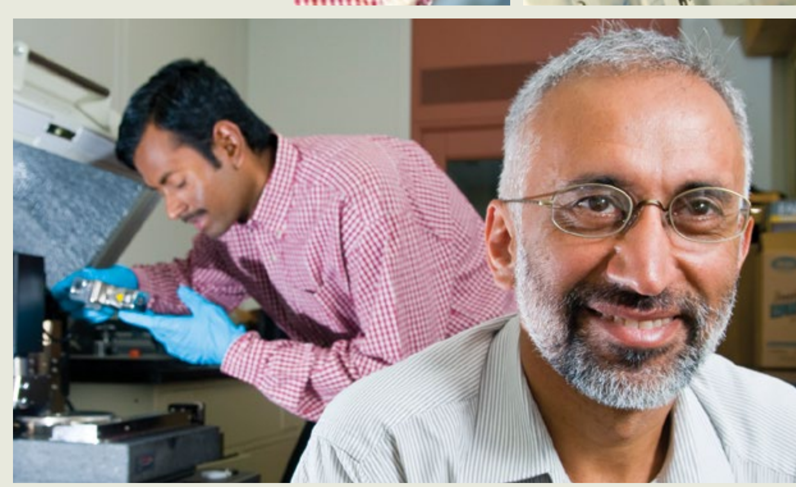
"The interesting discovery made by Tu and Zheng," says Jagota, "is that if you choose the DNA sequence correctly, it recognizes a particular type of CNT and enables us to sort that variety cleanly. This kind of practical improvement brings us closer to manufacturing possibility."

How does DNA recognize and sort types of CNTs? The DuPont-Lehigh team says this could be related to DNA's ability to form a structure different from its usual double helix when wrapping around the CNTs.

An alpha helix, like scotch tape wrapped around a pencil to form a tube, is a common shape seen in proteins, one of the main classes of biological molecules. Another common structure seen in proteins is the beta sheet.

"Such a structure is not known for DNA," says Jagota, "but we've shown that it is possible as long as you allow the DNA to adsorb on a surface. If the surface is cylindrical, like a CNT, you get a variant called the beta-barrel."

While the researchers do not have absolute proof, they say circumstantial evidence strongly supports their hypothesis that the DNA is forming this well-organized structure and that it recognizes a specific CNT in the same way that biological molecules recognize each other by structure.



Jagota, who directs Lehigh's bioengineering program, says the biomedical ramifications of the researchers' discovery are particularly exciting. One potential application for CNTs, for example, is to use them as substrates that can deliver biological molecules to cells in the body.

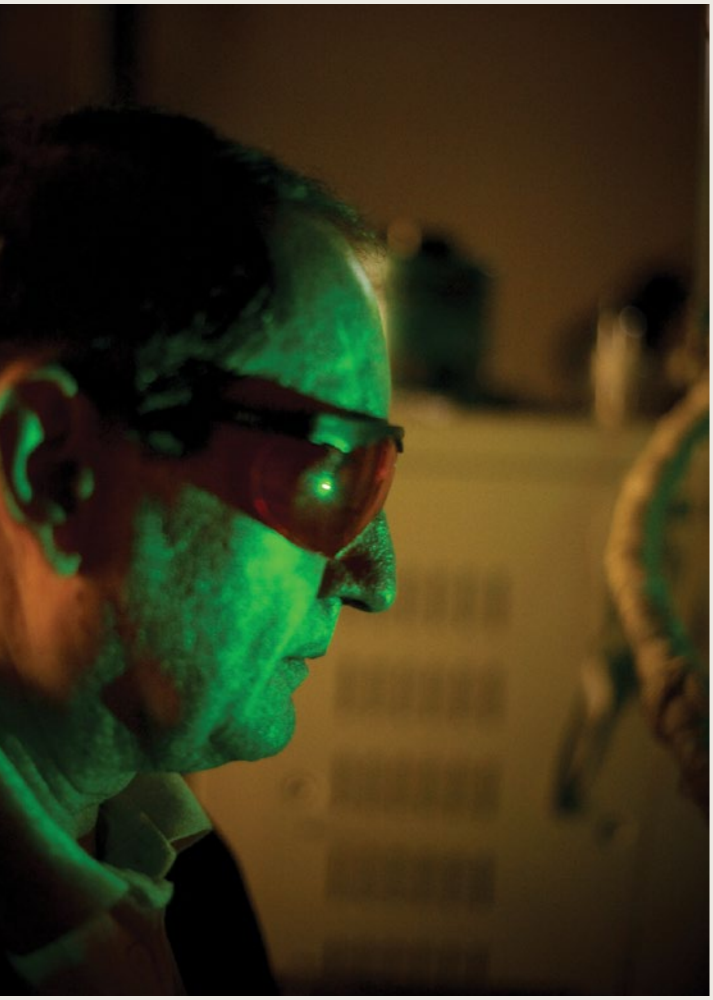
"We are very interested in the biomedical applications of this work," says Jagota. "What does this say about how DNA interacts with nanomaterials? Will they be harmful inside the body? Can we take advantage of the interaction for therapeutic applications? It's a big open field."

Manohar (top) and Jagota (foreground, bottom) believe DNA recognizes specific carbon nanotube types by structure.

A singular, molecular focus yields more effective catalysts

Advances in oil refining, drug and chemical production and environmental protection, says Israel E. Wachs, depend on understanding the relationship between a material's molecular structures and its catalytic properties.

Wachs, the G. Whitney Snyder Professor of chemical engineering, has spent much of his career investigating that relationship. He has written more than 300 articles, he holds three dozen patents and he is one of the most frequently cited researchers in his field. Wachs' article "Recent conceptual advances in the catalysis science of mixed metal oxide catalytic materials," published in 2005 in *Catalysis Today*, was the fifth most-cited paper in the field of catalysis that year and one of the 50 most-cited papers published in Elsevier's catalysis journals in 2004–08.



Wachs probes the relationship between a material's molecular structure and catalytic performance.

Catalysis, says Wachs, is indispensable to making products with as little waste as possible. Without the right catalysts in petroleum, chemical, pharmaceutical or environmental processes, he says, chances are you will not end up with an economical product. Thus, industry is counting on researchers to develop catalysts for new applications.

Wachs' patents include a process used in paper mills that converts methanol, a costly pollutant, into formaldehyde, a chemical that can be used in making particle board.

Sequence is vital to Wachs. He prefers to conduct fundamental studies of catalysts before testing them.

"Few take this approach or get as detailed as I do," he says. "That's why we discover not only new catalysts, but also new phenomena that help produce better catalysts. Because of this approach, we know at the molecular level how catalysts work and how they change in different environments. This understanding can give us the ability to make products faster and with less waste."

In one patented discovery, Wachs and his team found that by spreading metal oxides onto a stream of alcohol, they could make catalysts from pure natural materials without adding expensive precursors. This allows the catalysts, which usually lose their potency after a few years, to be rejuvenated.

Another discovery promises to help control the emission of nitrogen oxide (NO_x) from autos and electric power plants. NO_x is a greenhouse gas that also produces ground-level ozone pollution and acid rain. Funded by NSF, Wachs and his colleagues at Lehigh, Rice University and the University of Virginia are developing a molecularly engineered nanocatalyst that efficiently converts NO_x into benign nitrogen and water.

Wachs utilizes Raman spectroscopy and other advanced molecular techniques to see in real time how molecules and catalytic active sites interact while simultaneously analyzing reaction products online. This enables his group to determine directly the relationships between catalytic structure and catalytic activity. This technique has been termed *operando* spectroscopy, and Wachs appropriately named his Lehigh lab the *Operando* Molecular Spectroscopy and Catalysis Research Laboratory.

Wachs confesses to a zeal for detail.

"I find it intellectually satisfying. I get answers much faster by figuring out what makes a catalyst tick than by testing 1,000 catalysts."

His Ph.D. adviser at Stanford, Wachs says, exposed him to molecular-level research. His work at Exxon helped him understand complex industrial catalysts.

"I didn't understand how complex catalysts worked, and the only way to figure that out was to move on to Lehigh, where I would enjoy the academic freedom to ask and pursue fundamental questions."

In 2008, Wachs was chosen by the American Chemical Society to receive the George A. Olah Award in Hydrocarbon or Petroleum Chemistry for his contributions to catalysis over 30 years. Olah was the 1994 Nobel laureate in chemistry.

"Being at Lehigh, I interact with auto, mineral, chemical, pharmaceutical, environmental and petroleum companies," says Wachs. "It's a broader experience. What I enjoy most is the ability to establish the fundamental relationships between molecular structure and catalytic performance. If I know that relationship, I can design new and novel catalysts."

Unconventional cooling for overheated laptops

Consumers expect regular improvements in information technology, says Slava V. Rotkin, but these advances often come with a cost.

Take the laptop. Its billions of semiconductor electronic circuits grow ever tinier while the instrument's power and capacity increase. But heat generated by electric current can melt circuits and cause hardware to fail.

Rotkin and researchers at IBM's T.J. Watson Research Center and the Ioffe Institute in St. Petersburg, Russia, have developed a way of cooling carbon nanotube electronics by utilizing nonconventional radiation in a "near-field zone" just above the substrate on which the nanotubes rest.

The new method requires the substrate to be composed of a polar material like silicon-dioxide, says Rotkin, an associate professor of physics. It channels excess heat from the nanotubes into the substrate which, being much larger, can be more effectively cooled by the vents pushing cool air through laptops.

"Other methods of heat dissipation do not succeed in discharging heat from within the channel of the nanotube or nanowire," says Rotkin. "Our method enables the heat to leave the channel and move to the substrate, while also scattering the hot electrons. This constitutes a novel cooling mechanism without any moving parts or cooling agents."

Rotkin and his colleagues reported their results earlier this year in *Nano Letters*.

Because the nanotubes and substrate are made of heterogeneous materials, says Rotkin, their rate of thermal coupling, or heat release, is relatively low. This makes it difficult to dissipate heat from the nanotubes to the substrate through classical thermal conduction.

Rotkin and his colleagues instead utilize what they call surface phonon-polariton (SPP) thermal coupling by exploiting the high level of electron scattering that occurs in nonsuspended carbon nanotube transistors.

A wave called a surface polariton is caused by this electron scattering, says Rotkin. This polariton is particularly strong in the near field zone just above the substrate on which the carbon nanotubes rest.

"If you put a layer of carbon nanotubes in a near field zone," says Rotkin, "this enables the hot electrons to be scattered by the surface polariton and to give out energy to the substrate. Heat is dissipated into the substrate as radiation tunnels from the nanotube through the near field zone to the substrate.

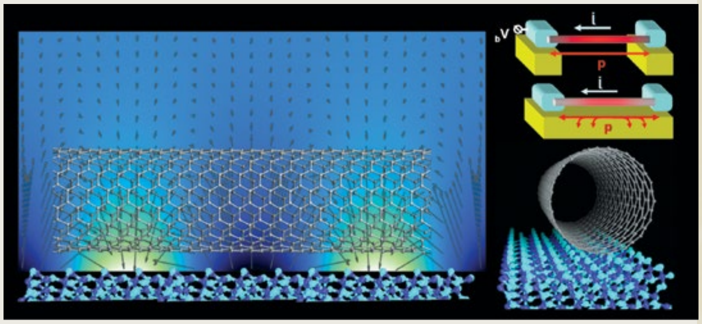
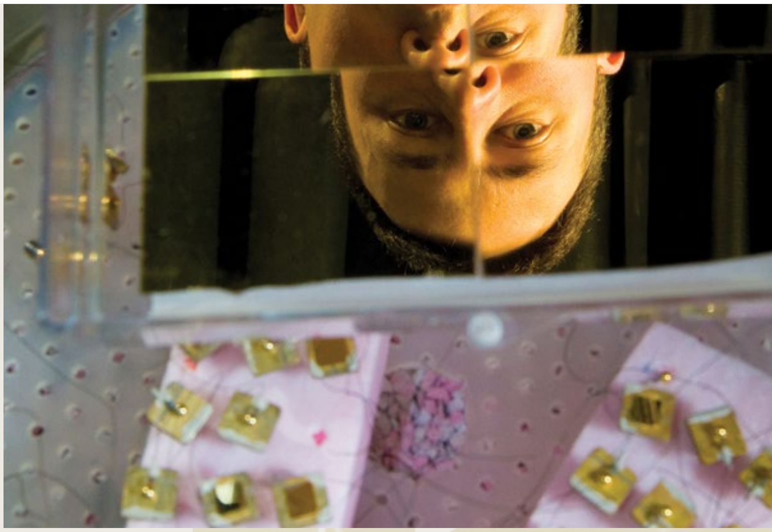


IMAGE BY ROTKIN

Near-field radiation field directly above the SiO_2 surface may be used to cool the nonsuspended nanotube transistors.

"Most semiconductor devices fabricated now have the nanotube or nanowire placed directly on a silica substrate, which is polar. With this mechanism, if the substrate is polar and if there's a small van der Waals gap, our new near-field channel totally dominates thermal coupling."

Rotkin is a primary faculty member in Lehigh's Center for Advanced Materials and Nanotechnology.



Vinci is proposing a hardened gold conductor to replace semiconductor RF switches.

Switch back in time

Rick Vinci and his colleagues have made a gold-based nanocomposite that could replace semiconductor switches in cell phones, computer wireless devices and other radio frequency (RF) applications. With funding from NSF, DARPA and NASA, they aim to develop high-reliability microelectromechanical (MEM) switches.

Semiconductors have replaced mechanical switches, says Vinci, an associate professor of materials science and engineering, because they have no moving parts and can operate endlessly.

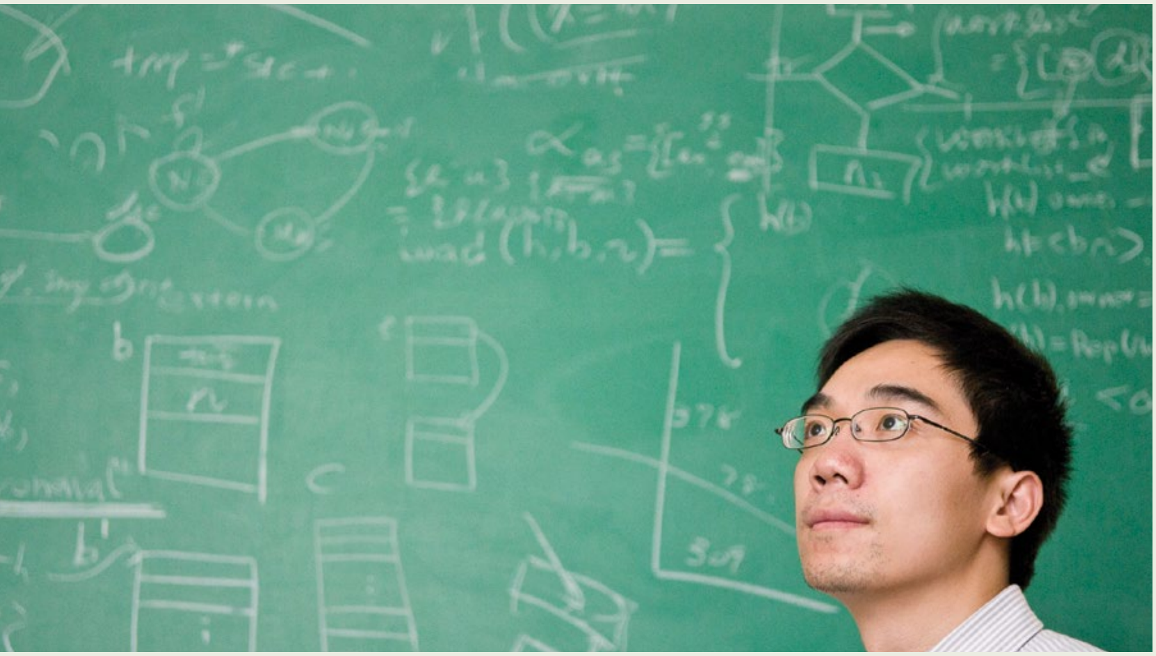
But there are advantages to mechanical switches. Semiconductor switches can leak RF signals even when turned off. Little leakage occurs in a mechanical switch that is turned off. And keeping a mechanical switch turned on requires little power.

To be used in RF devices, says Vinci, MEM switches must be hard enough to endure billions of on-off cycles but not so hard that they lose conductivity. Gold is a great conductor, but soft. Vinci's group spreads oxide particles evenly through the gold, so it hardens while maintaining conductivity. The process, called sputter deposition, has been used for many years, but Vinci's group is adding a twist.

They mix vanadium and gold to form an alloy while simultaneously exposing the film to oxygen. Vanadium reacts with oxygen to form vanadium oxide particles, which spread out and are buried by subsequent layers of the alloy.

"The nanoparticles disperse in the gold, which is still conductive and now is much harder," says Vinci.

Vinci works with James Hwang, director of Lehigh's Compound Semiconductor Technology Lab, and Profs. Herman Nied (mechanical engineering) and Bruce Koel (chemistry). They have reported their research in the *Journal of Applied Physics* and filed for a patent on the material.



Automated techniques, says Tan, help catch and patch software errors before programs are distributed.

Tackling the "trinity of troubles"

In September 2004, air traffic controllers at Los Angeles International Airport lost voice contact with 400 airplanes. Before communication was restored, five pairs of planes had narrowly avoided collisions.

The near-disasters occurred in part, says Gang Tan, because of a bug in a software-operated voice-switching and control system.

Tan, assistant professor of computer science and engineering, has spent a decade studying software security. His research has been funded by DARPA, NSF and the National Security Agency.

"Software is an essential part of daily life," says Tan, who specializes in vulnerabilities in large systems. "The safety of software can affect election results or online buying. So it is critical to get software right."

In his work, Tan contends with what security specialists dub the *trinity of troubles*:

Complexity. Microsoft's Windows 3.1 contained 5 million standard lines of code (SLOC) in 1993. Windows Vista (2006) required 50 million SLOC. Even rigorously tested code contains between 0.5 and 3 errors per 1,000 LOC, says Tan, and one flaw can disrupt a program.

Connectivity. Before the Internet, PCs existed in isolation; today virtually every computer is online. Hackers anywhere can access your data if your computer is not secure.

Extensibility. Not too long ago, users purchased software directly from developers or vendors. Now, plug-ins and other extensions pitched by third-party developers make it easy to download programs that could have a malicious intent.

Tan develops automated techniques to scan for errors in large software systems. His goal is to locate areas of vulnerability so developers can patch errors before they distribute software commercially.

"Our techniques seek to understand the semantics of a program, that is, what the software should do. If it deviates from this, our analyzer issues a warning.

"We look at the supposed behavior, or specification, of a system. We do a static analysis to try to understand the behavior of a system without running it."

Tan has conducted a static analysis of a software system containing 2 million LOC written in Java and 0.8 million LOC written in C.

"We have found more than 100 errors, and we have covered only a small part of the code," says Tan. "We are exploring the possibility of parallelizing our program so it can be run on multiple processors."

A supplement to common sense

As supply chain managers seek to optimize the movement of goods and services, it can make great sense to rely on common sense, says Larry Snyder. But in a small percentage of cases, a chain can defy common sense.

Snyder, assistant professor of industrial and systems engineering and codirector of Lehigh's Center for Value Chain Research (CVCR), proved this recently with a supply chain model customized for Bethlehem candymaker Just Born Inc. The model showed that minor changes to vehicle routing and facility locations could save the company tens or hundreds of thousands of dollars a year.

"Experienced managers tend to know what works well, but mathematical models can expose situations in which the commonsense approach is not optimal," says Snyder. "For example, one would expect that the most efficient way for Just Born to ship candy would be to use full-truckload shipping as much as possible, but it turns out that the company was doing too much truckload shipping and not enough less-than-truckload shipping. In supply chain management, exceptions are part of the equation."

Another outcome of the project was Just Born's recent decision to purchase the former Circuit City warehouse in Bethlehem and move its warehousing

Assigning priorities to wireless sensors

Wireless sensor networks, says Shamim Pakzad, are ideal for monitoring the stresses imposed on bridges by auto traffic, earthquakes and other loading events.

The sensors measure the steady stresses of traffic and the powerful, multidirectional loading of earthquakes, says Pakzad, the P.C. Rossin Assistant Professor of civil and environmental engineering.

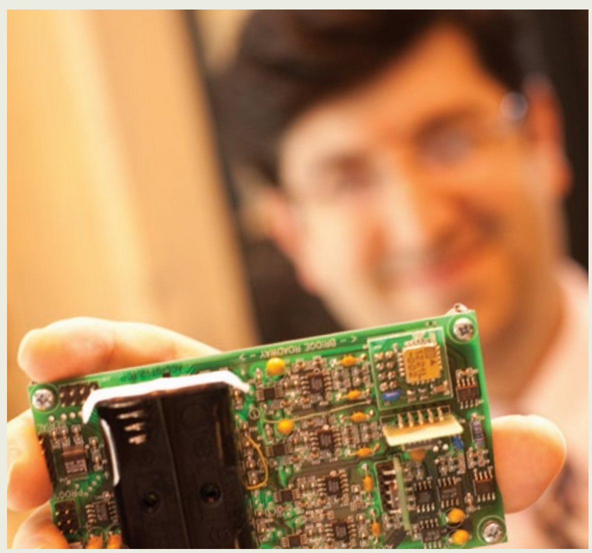
Because they are cheaper and easier to install and maintain than wired sensors, it is possible to fit a bridge with hundreds or thousands of wireless sensors, versus several dozen of the wired variety.

But challenges must be overcome before wireless networks realize their full potential, says Pakzad. Chief among them is priority-based task management.

Pakzad is working with Liang Cheng, associate professor of computer science and engineering, to enable a wireless sensor network to preempt a scheduled activity, such as monitoring traffic stresses, and switch to a more urgent task, such as monitoring responses to an earthquake or explosion.

"A structure can vibrate very quickly during an earthquake," says Pakzad. "You may need to take up to 100 samples per second. This produces a large volume of data that can quickly become unmanageable. We have to decide which data gets transmitted first, which does not need to be transmitted, and whether it is possible to send a summary of the data for later analysis."

Pakzad, who has an NSF grant, is developing software that optimizes the performance of sensor networks by dealing with network-



Wireless sensors, says Pakzad, are much easier to install and maintain than wired sensors.

ing, routing and time synchronization. His goal is to enable wireless networks to identify and communicate the locations on a bridge that have sustained damage, either from traffic or from earthquakes or other events.

"In the event of an earthquake, you need immediate analysis to tell you a bridge's condition, whether it can be operated safely, whether emergency response teams can cross it to get to various parts of the city.

"The measurements taken by each sensor need to be synchronized very accurately through a large network. Sensors must measure the vibrations and accelerations precisely at hundreds of points."

operations to that facility from Scranton. Using Snyder's model, Just Born, the maker of Peeps and other popular brands, determined it could not only improve efficiency with the new warehouse location, but could also persuade more candy companies to share the facility and the outbound trucks leaving its loading docks.

Twenty years ago, says Snyder, supply chain management was seen merely as a way to reduce costs, but today it is regarded as a competitive advantage that adds value for customers.

Error-control codes for network nodes

The Internet and other communication networks that contain connecting nodes (terminals, computers or switches) have undergone a revolution in the past decade.

Improvements in speed and efficiency have resulted in greater throughput, or the transmission of more data, and in popular applications that use multicast addressing to transmit data from one node to multiple nodes. One example of a multicast takes place when multiple users simultaneously download the same movie from the same Web site.

Traditionally, says Zhiyuan Yan, an assistant professor of electrical and computer engineering, data transmission has occurred when each node in a communication network stores a packet of information and forwards it to the next node.

In a newer, more advanced method of data transmission, nodes combine multiple incoming packets into a single packet and pass it on. "Combine-and-forward" data transmission, also called network coding, yields significant performance improvements in multicasts.

But there is a down side, says Yan. Errors due to noise, jamming or interference can undermine the integrity of the data transmitted in network coding. This threat is particularly severe for wireless applications.

Yan's group designs codes to detect or correct errors undermining network coding. The field is highly theoretical and mathematics-based. Yan and his students utilize three branches of mathematics – abstract algebra, finite field theory and combinatorics – to design classes of error control codes for network coding. They have led the way in adapting rank metric codes to error control in network coding. They also work with subspace codes and constant dimension codes.

Yan employs abstract algebra, finite field theory and combinatorics.

"Each type of code has its own parameters," says Yan. "We are one of the few groups working with rank metric codes and subspace codes."

Yan's group has published more than 50 articles in journals and conference proceedings. At IEEE's International Symposium on Information Theory this year in Seoul, South Korea, Yan presented three papers.

Yan receives funding from NSF and industry. He spent last summer as a visiting researcher at the U.S. Air Force Research Lab in Rome, N.Y.

A FRIENDLIER INTERFACE

TOOLSMITHS BRING COMPUTERS CLOSER TO HUMANS

James D. Foley '64 is the Stephen Fleming Chair in Telecommunications at the Georgia Institute of Technology. In 1991, he established the Graphics, Visualization and Usability Center (GVU) at Georgia Tech. In 1996, the center was ranked #1 by U.S. News and World Report for graduate computer science work in graphics and user interaction. Foley has served as CEO of Mitsubishi Electric ITA and sits on the advisory board to Lehigh's computer science and engineering department. He is a member of the National Academy of Engineering, past chairman of the Computing Research Association and lead author of "Fundamentals of Interactive Computer Graphics."

Q: ***You studied electrical engineering at Lehigh in the early 1960s. What attracted you to computer science?***

A: First, John Karakash [then department chair of electrical engineering and later dean of engineering at Lehigh] urged me to join the co-op program at Philco. That required work with digital logic. Second, I took a circuit synthesis course in summer school that involved a lot of programming. That got me hooked on computers. I also did a senior lab designing computer components and took a digital logic course.

Q: ***What was computing like at Lehigh then?***

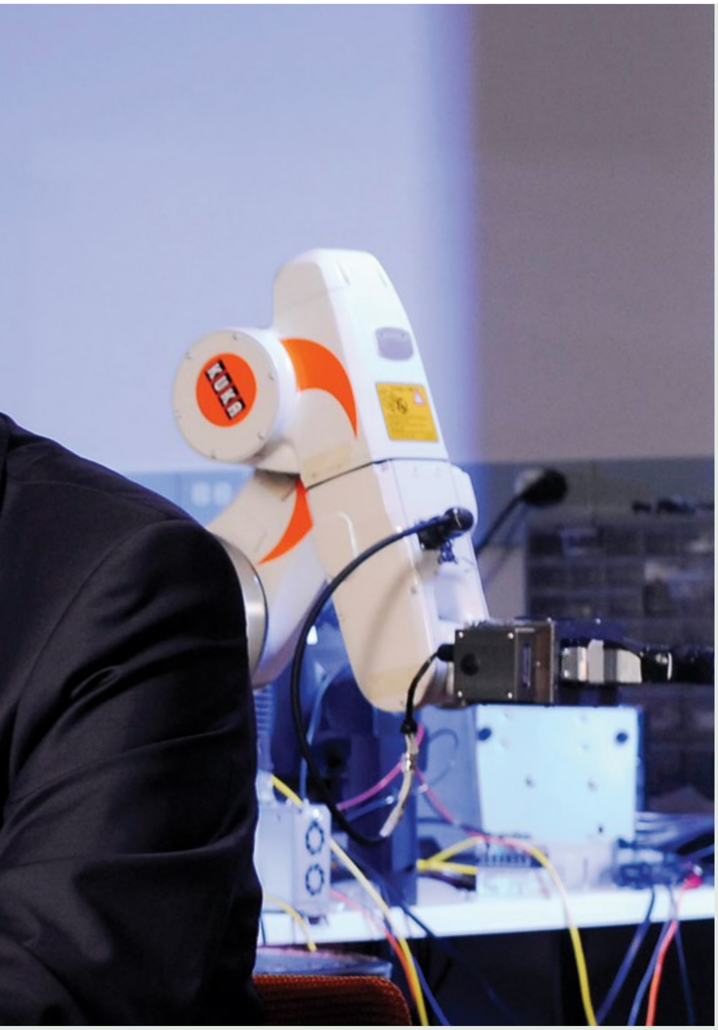
A: A lot of schools did not have computers, but Lehigh had a General Electric computer. I learned how to program on that computer. Without that GE computer, my career would not have taken the direction it has.

Q: ***You helped establish the fields of computer graphics and computer-human interaction. How did that come about?***

A: I have always been picture-oriented. In graduate school at the University of Michigan, I took a course in computer graphics. I first sought to use the computer as a tool to do 3-D engineering drawings and designs. Later, I became interested in making computers easy to use for people who don't speak "computer-ese." My research today is mostly about how people use computers.

Q: ***What challenges did you face in the early-days of computer graphics?***

A: Many companies then made computer graphics equipment and their computers were all different. An application developed for one computer had to be rewritten to run on another. There were no standards for graphics programs. One of the first things I worked on was standards. This made computer graphics programs more accessible because you could run them on different equipment.



Q: ***You coauthored "Fundamentals of Interactive Computer Graphics" in 1982. The book has been translated into 10 languages and is now in its third edition. Tell us about that.***

A: The book explored the underpinnings of computer graphics to write programs that interactively create drawings on the screen. It also addressed how to make realistic 3-D images and how to animate them, which is what computer-animated movies are all about.

Q: ***Your book also covered human-computer interaction (HCI).***

A: One thing that distinguished our book from others and made it successful was its treatment of HCI. Many people believe the book helped HCI become more accepted as a computer science. Some people considered HCI a "soft" discipline. But computers are tools and computer scientists are toolsmiths. How can you build tools for people if you don't know how they think about the tools and how they're going to apply them to solving problems?

A software design program, says Foley, should automatically generate user interfaces whose code can be repurposed to run on different platforms.

Q: ***What qualities make a good researcher?***

A: I've always tried to dig into a new area that hasn't been explored. It's more fun than incrementally improving something someone else did. Perseverance is another important characteristic. Not everything you try is going to work. Another critical attribute is intellectual honesty. You have to be optimistic that you will ultimately get an answer, but you must also question if you're going in the right direction.

Q: ***Which research project of yours was particularly important?***

A: The most significant work I've done is in developing software tools for HCI. Rather than just writing code to implement a user interface, you describe the operations a program can perform to a design program that creates a user interface design targeted to different devices such as cell phones or PCs. Because the user interface can be generated automatically, this lets you repurpose a code to run on different platforms without having to write a new interface.

I developed this in the mid-90s but it didn't get used then. Today, however, we have many devices with different form factors. There's more interest in moving an application quickly to a new form factor without having to completely redo the user interface. So my concept has been picked up in the past five years.

Q: ***Has the widespread use of computers changed the way people learn?***

A: I have the impression that the attention span of students is shorter because they are accustomed to being in front of a screen. I've been doing controlled experiments using prerecorded lectures shown to students on computer versus in-class lectures. The students learn better when they watch lectures at home on their computer. That's because they are able to control the pace. They can stop and restart, and even jump around. It's very much like browsing the Web. You can't do that with a lecture or even a book.

Q: ***Are the students coming out of high school prepared for your degree program at Georgia Tech?***

A: In general, no. They have not been exposed to computational thinking, in which you solve a problem by first breaking it into smaller subpieces. This is changing, but too slowly. We're still too focused on teaching programming in high school rather than on problem-solving methods and how they relate to the problems that need to be solved.

Q: ***What has been your best experience in teaching?***

A: One of my greatest achievements as an educator was receiving an award from the graduate students at Georgia Tech as the teacher who most makes students want to be a professor. What could be more satisfying?

Q: ***You've worked with industry and you've worked for a Japanese company. How did those experiences help you diversify your career and broaden your thinking?***

A: The experience in industry helped me see what is required to take an idea from the research lab to a real product. Mitsubishi provided a difference in four dimensions — time zone, distance, language and culture. I discovered the common bond that held people together was their interest in solving a problem.

Q: ***Your career has spanned most of the modern computer age. What do you think your most important contribution has been?***

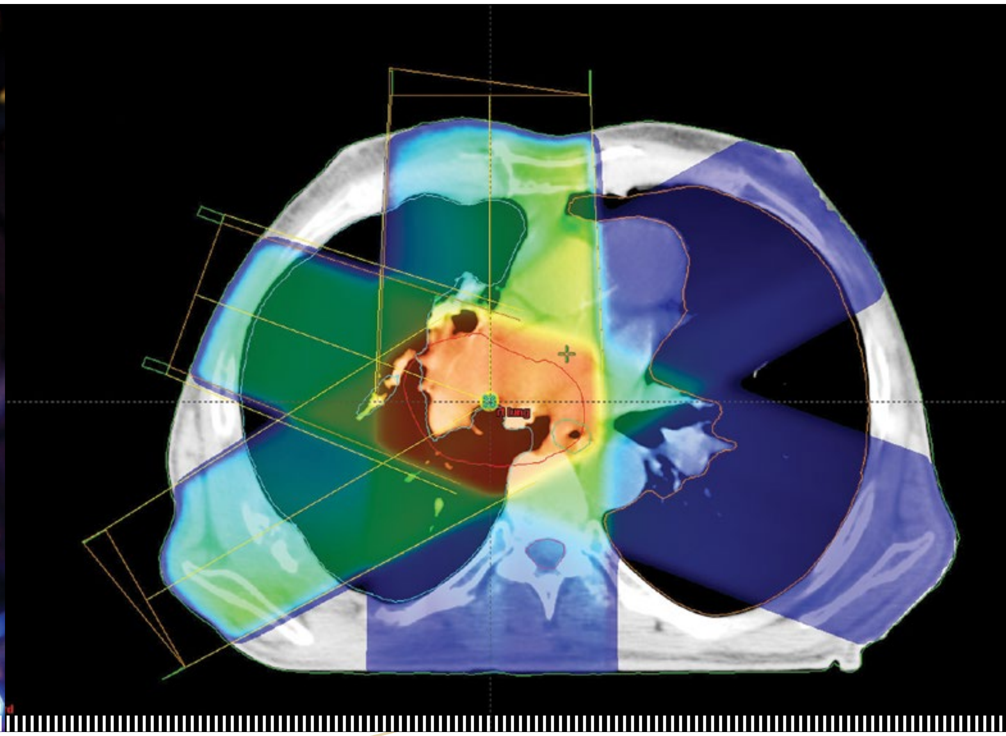
A: I am proudest of starting the Graphics, Visualization and Usability Center (GVU) at Georgia Tech. It was a critical factor in establishing HCI as a credible, recognized part of computer science.

Q: ***Which advances in computers have had the biggest impact on the world?***

A: Three important things have brought us where we are today. The microprocessor made computers inexpensive. The graphical user interface made computing accessible to nearly everyone. The Internet allowed computers to become a communication vehicle and means for information access and sharing. These things have transformed our personal lives, education, business and government.

Q: ***When you began your career, did you or anyone else have any idea these things would happen?***

A: No. I've never heard anyone claim to have seen the whole picture.



UNBOUNDED OPPORTUNITIES

IN WAYS LARGE AND NOT SO LARGE, RESEARCHERS ARE LEVERAGING HIGH-PERFORMANCE COMPUTING.

From mapping sunspots to mapping genomes to optimizing search engines, high-performance computing is uniquely positioned to illuminate the inner workings of natural phenomena and of human endeavors.

High-performance computing makes it possible to take systems more complex than we can imagine, model them mathematically, and analyze or improve these systems, often by solving countless equations in a second's time.

HPC, as it's called, lets car manufacturers run crash tests virtually, reliably and cheaply. It helps biologists simulate the activities of a cell and it enables physicists to model the flows of plasma in a nuclear fusion reactor. UPS and FedEx use HPC to select the best way, among millions of options, of routing thousands of drivers to their destinations.

HPC also brings rocket science to everyday life. One manufacturer of household appliances upgraded its computer cluster to solve the intertwined demands of product safety, supply chain management and protective packaging. A coffee maker used finite element analysis to model and solve problems caused by gas buildup when it switched from metal to plastic containers.

Lehigh will examine the state of the art in HPC when it hosts a workshop Oct. 5–6 titled “Computational Engineering & Science/HPC: Enabling New Discoveries.”

The following articles showcase some of the uses HPC has found at Lehigh.

Because of its very nature, says Ted Ralphs, associate professor of industrial and systems engineering, HPC is becoming more accessible. HPC tackles a large task by dividing it into subtasks and assigning these to processors that work in parallel to solve them. As these processors grow smaller and more affordable, says Ralphs, every workstation and desktop PC becomes a potential contributor to an HPC infrastructure.

“One big trend in HPC is that hardware is becoming more commoditized,” says Ralphs, who led Lehigh’s HPC steering committee for eight years. “It used to be that your PC was good only for basic functions and that you had to switch to a large machine to do a big job.

“Today, you can buy a group of PCs off the shelf, link them with a fast network connection and do perfectly acceptable parallel computing. Special processors are required less and less. Off-the-shelf equipment has enough power and memory for many tasks.”

Lehigh in the past four years has greatly expanded its HPC facilities with half a dozen strategic purchases of computer clusters, workstations and storage hardware. The university has also installed the Condor Project, which marshals all campus computing power – HPC facilities as well as the capacity of several thousand PCs in Lehigh’s public labs when those PCs are idle – to run large tasks.

“Condor is in constant communication with the computers on campus,” says Ralphs. “It identifies machines with capacity that’s not being used, and sends tasks to them. Not many campuses have this level of opportunistic computing that taps into commodity hardware.”

Computing and HPC underlie most of Lehigh’s major research efforts. Mathematicians use HPC to search for strange number pairs for security codes. Electrical engineers investigate signal processing as well as the energy costs associated with data warehousing. Biologists and bioengineers model the behavior of molecules, and geologists project climate change patterns.

Computer scientists use HPC to investigate computer-vision and pattern-recognition technologies. Mechanical engineers and physicists model the dynamic flow of fluids, including the plasma in nuclear fusion reactors. Physicists run numerical simulations to calculate the atomic structures and vibrational properties of material defects in semiconductors.

Computer clusters in Lehigh’s Computing Center (above left and right) enable research into a variety of topics, including the imaging, mapping and targeted radiation treatment of cancer (above center).

DIVIDING AND CONQUERING

Optimization problems, says Ted Ralphs, are tailor-made for HPC. Take the routing of delivery trucks. You must evaluate thousands of possible ways of assigning 100 drivers each to deliver 25 packages and identify the one solution that requires the fewest driver-miles.

“An optimization problem lends itself to a divide-and-conquer approach,” says Ralphs. “You divide a set of problems into portions and mathematically prove that certain portions will or will not yield useful information. This is a naturally parallelizable process because you give each portion of a problem to a different processor.”

Parallel processing, says Ralphs, thrives when all processors are busy all of the time doing productive work. Avoiding “down time,” however, is challenging when using a large number of processors. You do not know in advance how much work each portion of your problem will require. If half the portions are solved quickly, the computing capacity assigned to them will sit idle while the other portions are being solved.

“Idle time,” says Ralphs, “means your computing capacity is not paying its way.”

The answer, says Ralphs, is to shift data dynamically to underutilized processors in order to achieve efficiency. This becomes more difficult the more processors you use to solve a problem, and it makes demands on speed and bandwidth. Data must be shifted constantly, especially while solving a complicated problem. And this data management must not be allowed to consume

computing resources and undermine efficiency.

Ralphs tackles these challenges by writing "scalable" algorithms that determine how to move data around so each processor is always doing something useful to contribute to the overall computation.

"My goal is to write one algorithm with many procedures that covers the entire process no matter how many processors I'm using," he says. "I want one strategy that can be automated. If my method of shifting data changes because of the number of processors I'm using, this change should happen automatically."

Ralphs once wrote software to manage a task that required 2,000 processors. But scale is not his primary goal. Ralphs runs Computational Infrastructure for Operations Research, or COIN-OR, a repository of open-source software tools for optimization problems. People around the world have used his tools, and Ralphs takes delight in learning how his programs are applied. One of his favorite emails came from a man who said COIN-OR's optimization tools had helped overcome a water-delivery challenge in Africa.

"I develop fundamental tools and see what people do with them," Ralphs says. "I'm happy when I can produce something that helps someone solve a problem."

To maximize the efficiency of parallel processing, says Ted Ralphs, data should be shifted dynamically to under-utilized processors.

WHEN TIME SCALES CONFLICT

Life for atoms can be a contradiction in time scales. Take ceramic powders, for example. Scientists estimate their atoms vibrate as many as 10^{14} times per second, or one million times one million times one hundred.

When the powders are heated, or sintered, to form a solid material, says Jeff Rickman, a second, more leisurely motion results. Every 10,000 atomic vibrations or so, an atom hops from one location to another in the crystal lattice.

This hopping constitutes a phenomenon called diffusion, in which a material's molecules intermingle by randomly migrating from a region of higher concentration to one of lower concentration.

The difference between these two time scales, between fast and incomprehensibly fast, is of great consequence to Rickman, a professor of materials science and engineering who uses HPC to build computational models of diffusion.

Rickman studies the diffusion of aluminum and oxygen ions in aluminum-oxide (alumina), which is used in the manufacture of aluminum and in advanced ceramics, catalysts, tools and engine parts. Diffusion plays a role in creep, in which a solid material deforms because of low-level stresses.

Rickman's goal is to learn how a tiny amount of an impurity can alter diffusion and other transport properties. He has conducted tensile loading experiments to examine creep and oxidation, and he is constructing computational models to learn how impurities affect diffusion.

Because the ions in alumina are coupled, Rickman must write equations of motion for all the pairs in a system and solve the equations together. "Everything in this system is interconnected," he says. "Each ion exerts force on its neighbor. If one moves, both are affected."

Rickman's equations must also take into account the vastly different speeds at which atoms hop and vibrate.

"Diffusion is a slow process compared with the vibrations of atoms. We are interested in the atoms that are hopping but we must also watch the atoms that are shaking. To integrate the equations, we have to bridge time scales. To solve the equations, we have to follow the fastest thing happening even if we're not interested in it.

"And because we're studying transport over distance, we have to wait for many hops to occur before we can make a meaningful calculation about diffusion."

Rickman writes parallel codes to simulate the phenomena in the system he is studying. "We're looking at a relatively large system. This implies the need to subdivide the system into parts, to use different processors and to do this in such a way that processes occurring almost independently can be modeled almost in parallel."

Rickman uses Lehigh's HPC facilities as well as those at the Pittsburgh Supercomputing Center. He collaborates with Helen Chan and Martin Harmer, professors of materials science and engineering. The group receives funding from the Office of Naval Research.

FATIGUED CANTILEVERS

Take a second look at the cantilevered traffic signals and highway signs that you see everywhere on roads and freeways. The welded connections that support these structures are vulnerable to fatigue cracking from the cumulative effects of winds and breezes. The issue has become urgent in the U.S., especially in the West and Midwest, where signs have fallen and structures have collapsed.

Lehigh's ATLSS (Advanced Technology for Large Structural Systems) Center is combining HPC with full-scale lab tests to develop specifications for the design and fabrication of new sign and mast structures and for the retrofitting of existing structures. The four-year project is funded by the American Association of State Highway and Transportation Officials and the Federal Highway Administration.

The ATLSS group is conducting 100 to 110 tests on 80 structures. The group has also conducted simulations of 18,000 mathematical models of the structures and the welded connections using ABAQUS, a suite of finite-element analysis software. Each model contains about 40,000 degrees of freedom, a term that refers to the number of equations that must be solved at each iteration.

The project makes use of two HPC architectures in Lehigh's Computing Center. The SMP (Symmetrical Multi-Processor) computing facility contains a large number of processors and a shared memory in a single machine. The 40-machine Beowulf cluster enables parallel processing of full-scale structural systems by parceling parts of one large analysis out to many different machines.

The lab tests and computational simulations complement each other, says ATLSS senior research scientist Sougata Roy, who oversees the project with ATLSS director Richard Sause.

HYBRID SIMULATIONS

In Lehigh's ATLSS (Advanced Technology for Large Structural Systems) Center, researchers use HPC to help design structures that can withstand earthquakes without damage. On a three-story building, they have installed diagonal braces fitted with dampers made of elastomeric, viscous, magnetorheological and other materials currently used in shock absorbers and suspension systems.

The researchers combine physical experiments with numerical models in a "hybrid simulation" that evaluates the performance of a structural system and all of its structural elements under earthquake excitations. The project, directed by James Ricles, professor of structural engineering, along with ATLSS director Richard Sause, is funded by NSF through its NEES (George E. Brown Jr. Network for Earthquake Engineering Simulation) program.

Hybrid simulation, says Ricles, is useful when some parts of a system are understood well enough to be mathematically modeled while other parts are not and must be tested physically in the lab. In the current project, a grid of parallel processors, or experimental coordinator, imposes the effects of earthquake loading simultaneously on the braces and dampers in the lab and on a computer model of the building and remaining elements. The laboratory and computer models are coupled through their common degrees of freedom, or equations. The coordinator and both portions of the test are linked by a local area network that transmits messages in nanoseconds over a fiber-optic cable.

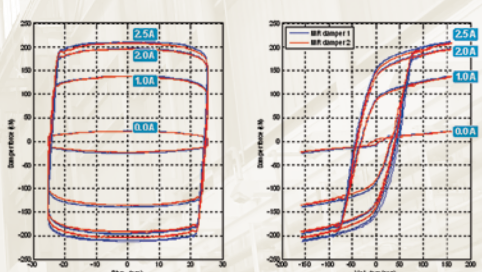
Tests are run in real time to obtain more accurate data about the dampers, whose "rate-dependent" materials respond both to the cumulative effect of stresses and to the speed at which they are imposed.

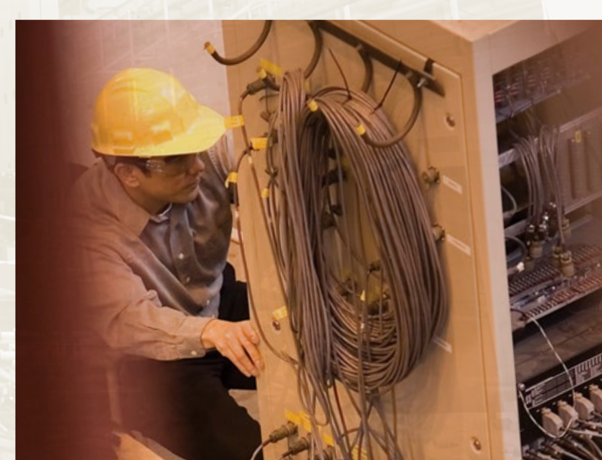
The experimental coordinator commands hydraulic actuators to impose deformations on the dampers and braces approximately 1,000 times a second and from multiple directions. These "command displacements" simulate the multidirectional loading and ground motion, or acceleration, caused by an earthquake. A numerical integration algorithm calculates the displacements and the responses they elicit from structural elements, dampers and braces. The coordinator, says Ricles, must solve equations of motion and prepare command displacements every one-thousandth of a second in a recursive manner.

One goal is to determine how well dampers can enhance the seismic performance of a structural system. If successful, says Ricles, the dampers will enable beam-to-column connections and other elements to move and then return to their original position following an earthquake. This would allow a structure to survive an earthquake without damage or loss of life while avoiding costly repair time when it cannot be used.

Future hybrid simulations, says Ricles, will be performed for each type of earthquake ground motion and for a variety of structural designs. HPC will enable researchers to conduct large-scale simulations to evaluate systems with more variables and equations.

Researchers in Lehigh's ATLSS Center use HPC to design and test technologies that allow structures to survive earthquakes without loss of life or damage.





"Because lab tests are expensive and time-consuming, you can do only a limited number of them. Simulation enables you to extend your findings, but it goes only so far. Even the most sophisticated calculations will not produce the right result until you can confirm your mathematical model with experimental results.

"You can then use mathematical modeling to project the results of lab tests to a similar, but distinct, set of tests. As more experimental data comes in, you refine your model to improve its predictions."

Advances in computational capabilities in the last 15 years or so have enabled engineers to analyze and simulate more realistically the response of an entire structure and its design to different types of failure modes.

"Our goal," says Roy, "is to define the infinite life threshold of the variation of the critical connections in these structures so that we know that no fatigue-induced failure will occur during their design lifetime. This will enable future standards to specify how many cycles a structure can sustain."

TO SHADE OR TO SHINE

HPC has long played a role in the imaging of tumors, says Tamas Terlaky, but it has not yet reached its full potential.

"Massively parallel computing technology gives us an optimal image of the tumor and the healthy organs alongside it," says Terlaky, the chair of the department of industrial and systems engineering. "Once you have this image, you have to decide how to radiate the tumor. Twenty years ago, radiologists used a large gamma ray beam that revolved around the body, radiating from different angles. But this was a uniform beam that often burned healthy tissue and tumor alike."

Advances in computational modeling enable today's radiologists to limit this damage by modulating the intensity of the beam as it moves in an arc around the tumor. This Intensity-Modulated Radiation Therapy (IMRT) is achieved by focusing the beam through a grid of pinholes as small as 1 mm across that can be shaded. Radiologists and medical physicists solve linear equations to determine which holes should be shaded, and by how much, at a large number of positions along the arc.

"You need to decide where to shade and where to shine from each position as the beam moves around," says Terlaky. "This involves millions of variables and is far beyond what a medical doctor by intuition can do. You need a mathematical model capable of solving millions of equations to calculate the optimal pattern of radiation."

This model must also overcome the uncertainties inherent in radiation therapy, says Terlaky. As your tumor is being radiated, for example, you are breathing and your body is moving. And the image on which your mathematical model is based is no longer accurate, as you will have gained or lost weight since it was taken.

To develop models robust enough to deal with these uncertainties, Terlaky uses SeDuMi (SelfDualMinimization), a software package that solves optimization problems over symmetric cones and can link the linear and nonlinear aspects of IMRT.

"Thanks to SeDuMi, we can now solve optimization problems that are

UNRESTRICTED QUANTUM CODES

Complex problems in optimization and encryption that now tie up supercomputers for years will one day be solved in seconds, some have predicted, by quantum computers.

But this will not come to pass, says Tiffany Jing Li, without quantum error-correction (QEC) codes that let quantum devices compute reliably in the fragile quantum world. Li, an associate professor of electrical and computer engineering, has invented several new classes of QEC codes with support from NSF.

Conventional computers encode information as bits. Quantum computers encode data in electrons, photons, nuclei and other quantum states as quantum bits, or qubits. A bit can exist in two different states – 1 or 0. A qubit can be 1, 0, or a "superposition" of one over the other. Additional states are enabled by entanglements between qubits.

But in the quantum world of atoms and subatomic particles, the slightest noise degrades signal and data quality and undermines the ambiguity and entanglements that give quantum computing its potential. This frustrates efforts to achieve fault-tolerant quantum computing using conventional error-correction codes, says Li.

In conventional computers, says Li, errors that occur during transmission can be corrected by encoding data to introduce redundancy. When transmission is completed, the original data is retrieved through decoding.

The "no cloning theorem" of quantum mechanics, however, does not allow replication of a quantum state, because that which is arbitrary and unknown cannot be copied. Another rule postulates that observation and measurement change the quantum state and make restoration impossible.

This would seem to preclude the possibility of QEC coding. If a decoder cannot accurately observe a possibly corrupted qubit value, it cannot develop an appropriate decoding procedure.

In 1995, three researchers overcame these obstacles by showing that the information in one qubit could be spread onto an entanglement of qubits. Their CSS stabilizer code is the basis of most QEC codes yet developed.

"The vast majority of existing quantum codes is restricted to this special formalism," says Li. "Unrestricted forms offer richer coding choices much bigger and more complicated than ever before, and we can solve them much more quickly," says Terlaky, who directed McMaster University's School of Computational Engineering and Science in Ontario before joining Lehigh's faculty in 2008.

"Fifteen years ago, there was no way to solve these problems. SeDuMi has helped us solve a small fraction of them."

INVISIBLE ADVERSARIES

Only a minority of Internet users, says Brian Davison, click past the first page of a list of search results, and barely 10 percent make it to the third page. Hundreds of millions of searches are conducted daily and a query can yield millions of results. Factor in human nature and you have the ingredients for an invisible and adversarial contest: While search engines seek to provide accurate results for clients, shady content providers use link-bombing, blog spam, comment spam and other gimmicks to falsely boost their rankings.

The phenomenon has given rise to a field of study called adversarial information retrieval (IR), which helps search engines identify Web sites that manipulate search engine rankings. Adversarial IR researchers have held five annual AIRWeb workshops; Davison, an associate professor of computer science and engineering, organized the first three and gave the keynote address at AIRWeb (2009 in Madrid, Spain).

Davison collaborates with researchers from Yahoo, Google and Microsoft to improve the quality of search engine rankings. In his work, which is supported by an NSF CAREER Award and by Microsoft, he writes algorithms that perform contextual link analysis to help search engines achieve more accurate rankings. This type of analysis gauges the reputation of a Web site by evaluating the sites from which it is linked.

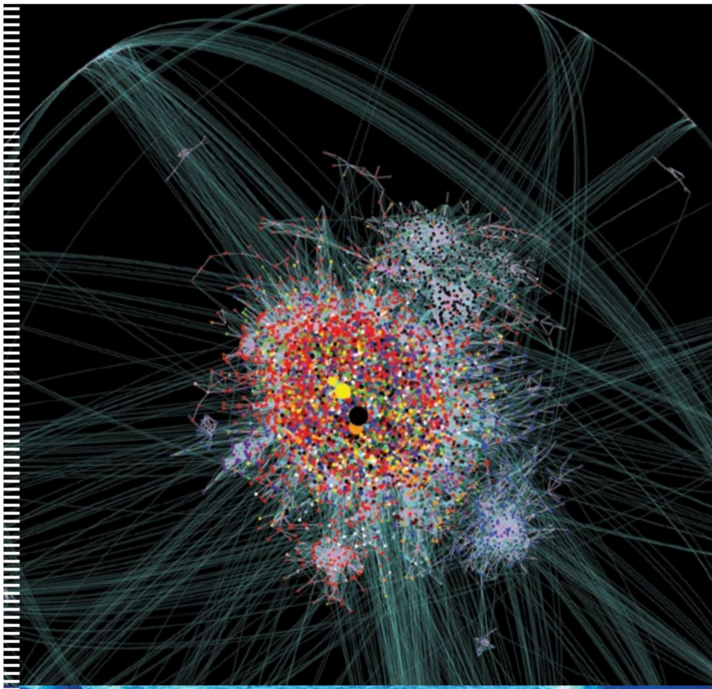
"If 50,000 pages match a query," says Davison, "which are most authoritative? Search engines track the number of times Web page authors link to a page. We try to be more intelligent by factoring in the topics of the sites that link to the pages that come up in a search. We determine this by following links on the Internet. The links that a Web site chooses are regarded by search engines as expressions of popularity."

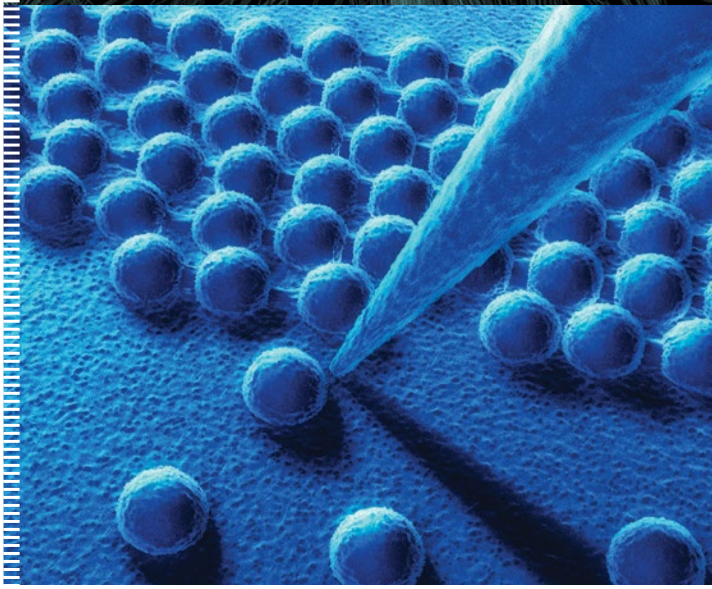
Davison analyzes hundreds of millions of Web pages. Hoping to push that number to one billion, he has assembled dozens of hard drives and tens and eventually hundreds of terabytes of storage. "To follow the Web in a believable way, we work with ever-larger collections of data. As a result, we need machines with lots of memory. We can perform our calculations much faster if our entire set of data fits in the memory."

Fighting search engine spam, Davison said at AIRWeb 2009, is like playing a high-stakes game of chess against an opponent who constantly changes the rules.

"The Web is becoming the sum of human knowledge. It's vital to know what information can be considered true or objective."

Search-engine optimization and the modeling of atomic vibrations (bottom) are two other applications of HPC-supported research at Lehigh.

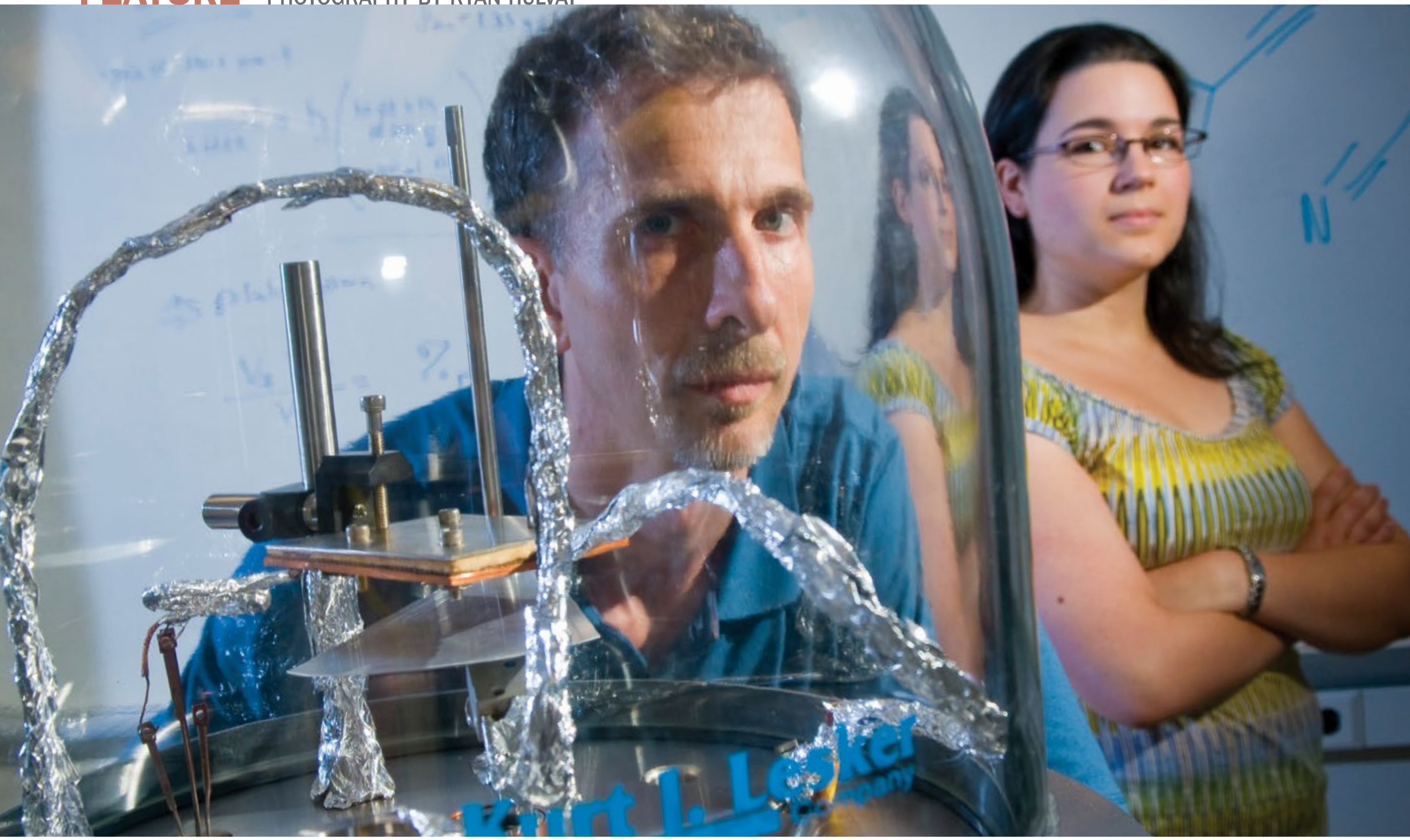




and better error-correction performances, but formal methods are lacking to construct them."

Two years ago, Li and her group invented the first class of unrestricted (non-CSS) stabilizer LDPC (low-density parity-check) codes based on classical binary codes. In contrast to previously reported design methods, many of which resulted in only a single code with a fixed rate and length, the new design developed by Li's group revealed a rich family of codes with a wide range of rates and lengths.

More recently, Li and her group have invented systematic ways of constructing unrestricted and restricted stabilizer codes. They have designed the first feasible quantum decoding algorithm for unrestricted stabilizer convolutional error-correcting codes, and they have successfully simulated and demonstrated the codes' error-correction performance.



Biaggio (above left), Esembeson (inset) and Michelle Scimeca (above right) collaborate with researchers in Germany, Belgium and Switzerland.

A TELECOM BREAKTHROUGH

ORGANIC MOLECULES GIVE SILICON CIRCUITRY ALL-OPTICAL SWITCHING CAPABILITY.

The next time an overnight snow begins to fall, take two bricks and place them side by side a few inches apart in your yard. In the morning, the bricks will be covered with snow and barely discernible. The snowflakes will have filled every vacant space between and around the two bricks.

What you will see, says Ivan Biaggio, resembles a phenomenon that, when it occurs at the smallest of scales on an integrated optical circuit, could hasten the day when the Internet works at superfast speeds.

Biaggio, an associate professor of physics, is part of an international team of scientists and engineers who have developed an organic material with an unprecedented combination of high optical quality and the strong ability to mediate light-to-light interaction. The researchers have integrated this material with silicon technology so it can be used in optical telecommunication devices. They reported their findings recently in *Nature Photonics*.

The new material is composed of small organic molecules with high nonlinear optical susceptibilities. It mimics the behavior of the snowflakes covering the bricks when it is deposited into the slot, or gap, that separates the silicon waveguides that control the propagation of light beams on an integrated optical circuit.

Just as the snowflakes, being tiny and mobile, fill every empty space between the two bricks, Biaggio says, the molecules completely and homogeneously fill the slot between the waveguides. The slot is tens of nanometers wide.

"We have been able to make thin films by combining the molecules into a material that is perfectly transparent and flat, and free of any irregularities that would affect optical properties," says Biaggio.

The slot between the waveguides is the region where most of the light guided by the silicon propagates. By filling the slot, say Biaggio and his collaborators, the molecules add an ultrafast all-optical switching capability to silicon circuitry, creating a new ability to perform the light-to-light interactions necessary for data processing in all-optical networks.

The nanophotonic device that is obtained in this way, says the group, has demonstrated the best all-optical demultiplexing rate yet recorded for a silicon-organic-hybrid (SOH) device. In tests, the novel hybrid device was able to extract every fourth bit of a 170.8-gigabit-per-second telecommunications data stream and to demultiplex the stream to 42.7 gigabits per second.

Biaggio collaborates with researchers from the Institute of Photonics and Quantum Electronics at the University of Karlsruhe in Germany, the Photonics Research Group at Ghent University in Belgium, and the Laboratory for Organic Chemistry at the Swiss Federal Institute of Technology (ETH) in Zurich. Biaggio is affiliated with Lehigh's Center for Optical Technologies (COT). Another group member, Bweh Esembeson, earned a Ph.D. in physics from Lehigh and is now an applications engineer with Thorlabs Inc. in New Jersey.

A NONLINEAR OPTICAL ANSWER TO BANDWIDTH DEMAND

As Internet users demand greater bandwidth for faster communications, scientists and engineers are working to increase the speed at which information can be transmitted and routed along a network. They are hoping to achieve a major leap in velocity by designing circuits that rely solely on light waves to process data.

At present, data must be converted back and forth from optical signals to electrical signals in order to manage its progress within an optical telecommunication network. This limits the flexibility and speed of optical telecommunication. All-optical circuits, experts say, could unleash the full potential of optical telecommunication and data processing.

All-optical circuits require nonlinear optical materials with high optical properties. A nonlinear optical response occurs in a material when the intensity of light alters the properties of the material through which light is passing, affecting, in turn, the manner in which the light propagates.

Biaggio's group is working with an organic molecule called DDMEBT that possesses one of the strongest nonlinear optical responses yet observed for its relatively small size. The molecule can condense from the vapor phase into a bulk material. The high, off-resonant bulk nonlinearity and large-scale homogeneity of this material, says Esembeson, represent a unique combination not often found in an organic material.

The DDMEBT bulk material possess 1,000 times the nonlinearity of silicon, but is difficult to flexibly structure into nanoscale waveguides or other optical circuitry. Silicon, on the other hand, is structurally suited to the dense integration of components on photonic circuit devices. And silicon technology is mature and precise. It enables the creation of waveguides whose nanoscale flatness facilitates the control of light propagation.

"With pure silicon," says Biaggio, "you can build waveguides that enable you to control light beam propagation, but you cannot get ultrafast light-to-light interaction. Using only silicon, people have achieved a data switching rate of only 20 to 30 gigabits per second, and this is very slow.

"We need higher-speed switching to achieve a higher bit rate. Organic materials can do this, but they are not terribly good for building waveguides that control propagation of tightly confined light beams."

THE BEST OF BOTH WORLDS

To combine the strengths of the DDMEBT and the silicon, Biaggio's group has fashioned SOH waveguides in which the silicon waveguide are covered with DDMEBT.

"We start with a silicon waveguide designed to guide the light between two silicon ridges," he says. "Then we use molecular beam deposition to fill the space between the ridges with the organic material, DDMEBT. This creates a dense plastic with high optical quality and high nonlinearity.

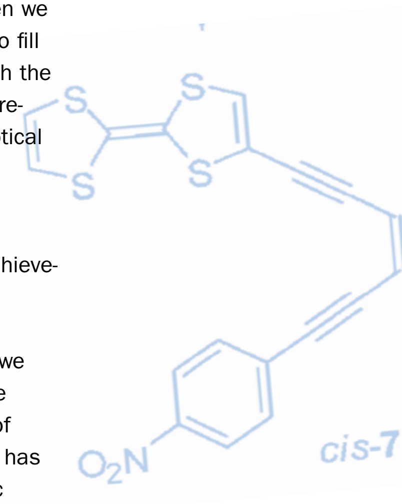
"We combine the best of both methods."

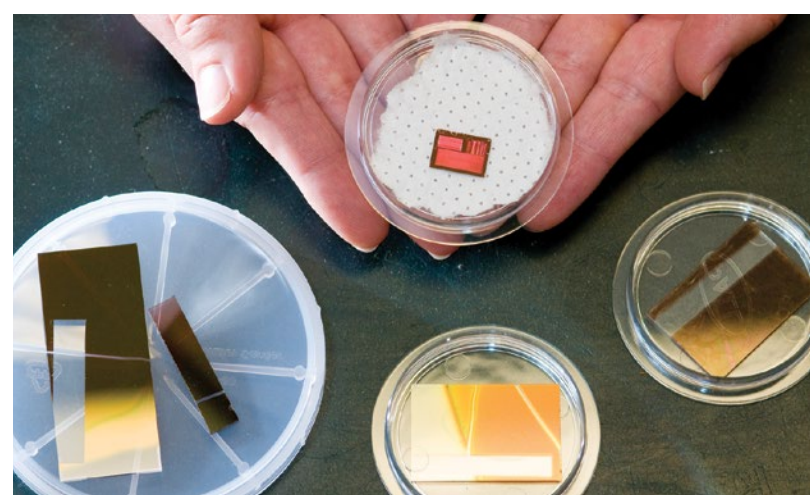
One of the group's singular achievements, he says, is the filling-in process.

"The key question is whether we can put the DDMEBT between the two silicon strips. There is a lot of research in this area, but no one has yet been able to make an organic material completely and homogeneously cover such a silicon structure so that it spreads out and fills all the spaces. Homogeneity is necessary to prevent light scattering and losses.

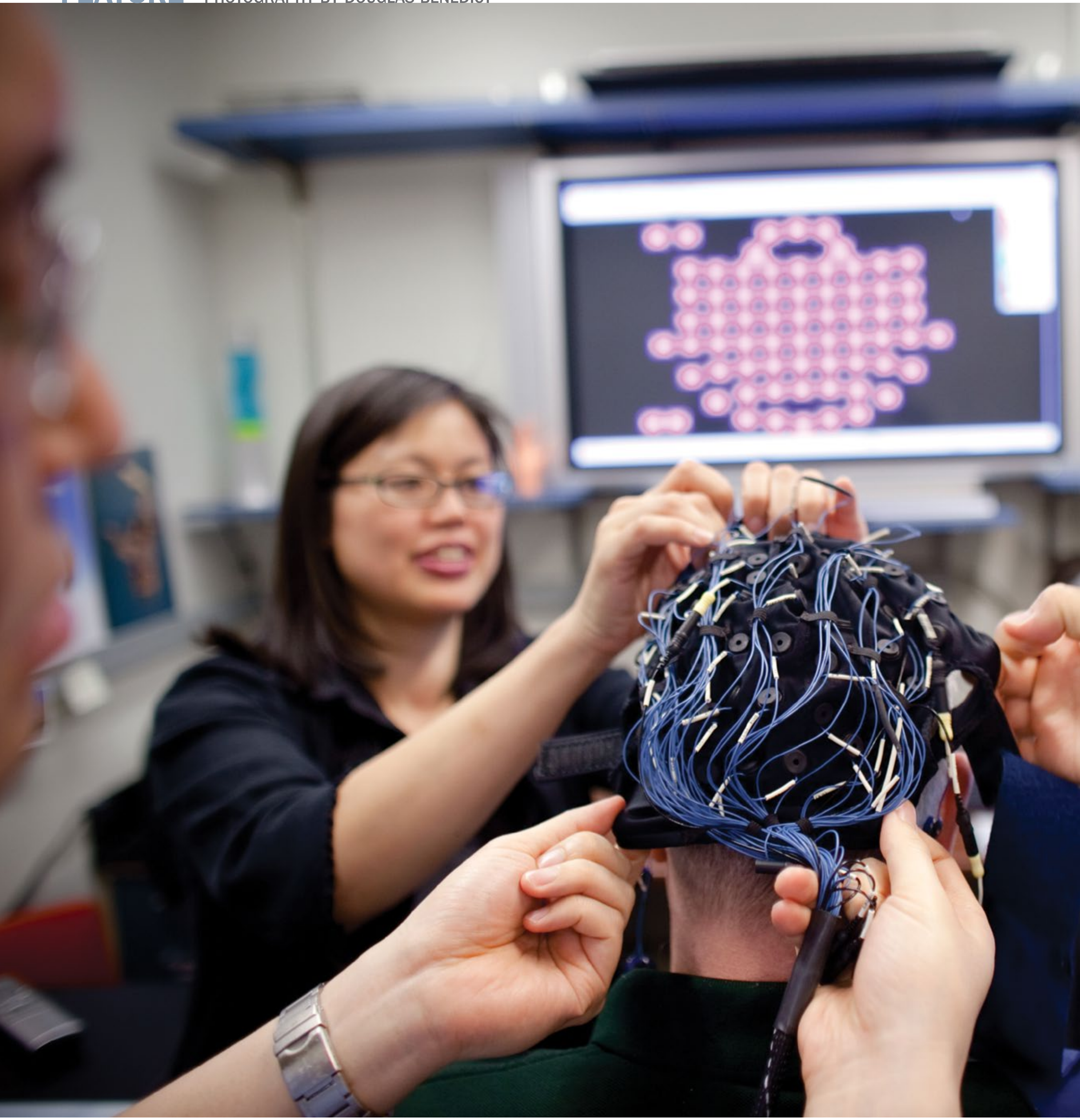
"We achieved this by using a molecular structure that decreases intermolecular interactions and promotes the formation of an homogeneous solid state. We then heated the molecules to a vapor phase and used a molecular beam to deposit the molecules on top of the silicon structure. The molecules were able to homogeneously fill the nanoscale slot between the silicon ridges and to cover the whole structure we needed to cover.

"Our collaborators in Karlsruhe were able to reliably switch individual bits out of a 170.8-gigabit-per-second data stream. This is impressive, but the organic material would be able to support even faster data rates."





By homogeneously filling the slot separating the silicon waveguides, the new material adds an ultrafast all-optical switching capability to silicon circuitry.



CLOSING THE LOOP

RESEARCHERS FROM LEHIGH AND JOHNS HOPKINS are measuring the effect of sensory feedback on the transmission of brain signals. Their goal is to help people with brain damage regain lost function.

Roy Loya is a tax attorney who has piloted airplanes, worked as an aeronautical engineer and traveled to most of the corners of the world.

Today, sitting perfectly still with 64 electrode sensors attached to his scalp, he is summoning the waning powers of his mind.

Loya has struggled for 10 years with ataxia, a degenerative condition that robs the brain of its ability to coordinate the body's fine motor movements. He cannot stand on his own, walk or hold a pen. His speech is slurred and raspy.

But Loya is conceding nothing to illness. Today, guided by a team of researchers, he is marshaling his brain signals to do what his body no longer can.

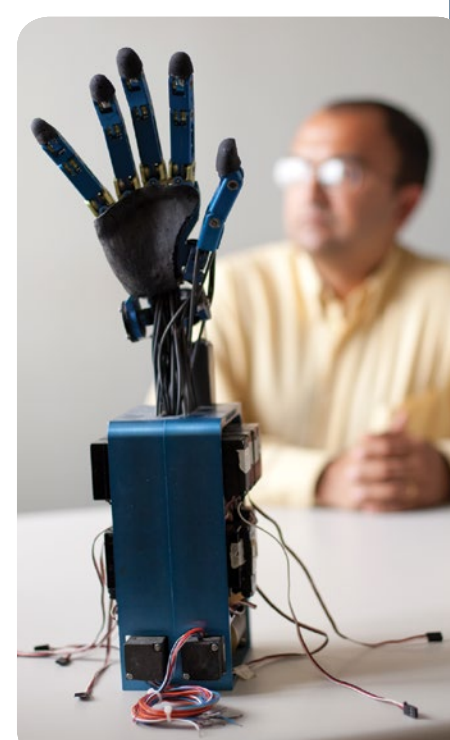
Without flexing a muscle, Loya imagines he is moving his right hand. This generates brain signals, which are conveyed to an amplifier and an electroencephalograph (EEG). A computer processes the signals and carries out their intention. The results play out on a 40-inch TV, where a cursor inches down from the middle of the screen until it hits a rectangular target at the bottom.

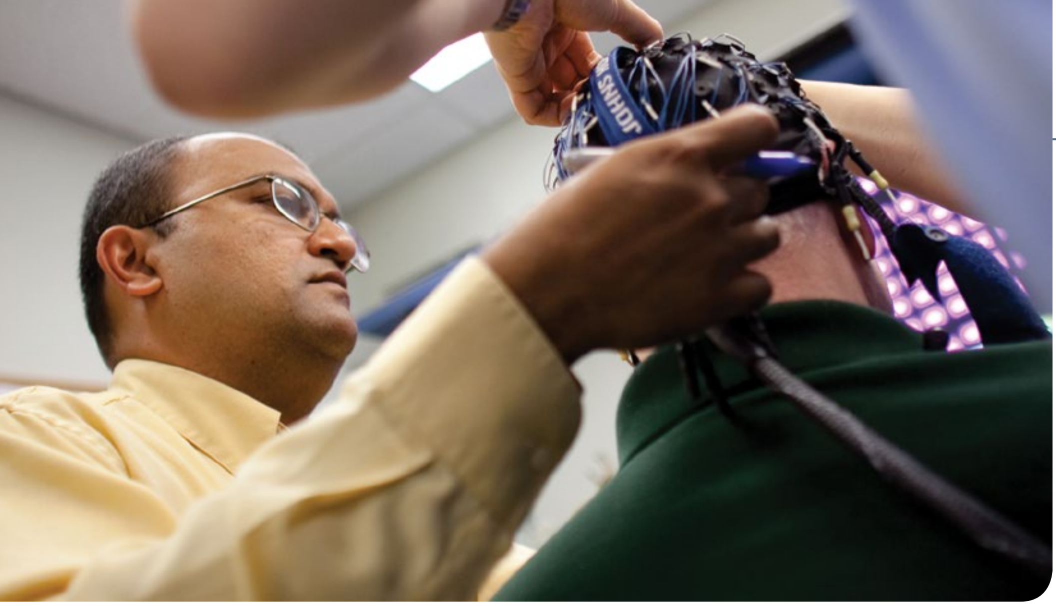
Loya next focuses mentally on a left-hand motion, and the cursor moves slowly toward a target at the top of the screen.

Loya is seated in a neuroengineering lab at Johns Hopkins University's School of Medicine. Minutes pass as he performs each task. Six researchers stand quietly around him, moving only to read the signals displayed on the computer or to adjust the signal-processing software.

The research team is led by Sarah Ying and Nitish Thakor of Johns Hopkins and Mayuresh Kothare of Lehigh. Ying, an assistant professor of neurology and ophthalmology at the Johns Hopkins Hospital, is an expert in ataxia, dizziness and eye movement abnormalities.

Roy Loya (seated, left) is learning to control his brain signals with help from Sarah Ying (left) and Mayuresh Kothare (below).

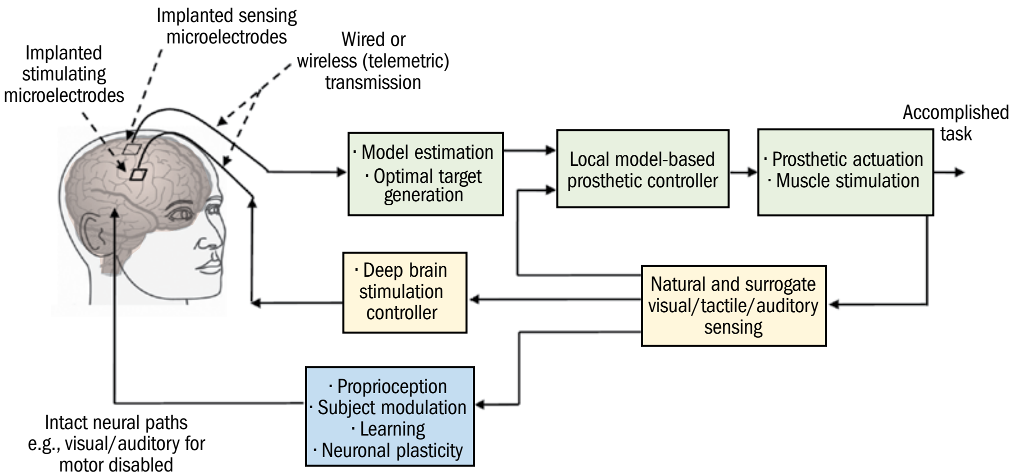




Kothare helps Loya prepare for his first trial with brain-computer interface (BCI) technology.

She has worked with Loya for seven years. Thakor, professor of biomedical engineering and neurology, directs Johns Hopkins' Neuroengineering and Biomedical Instrumentation Lab. Kothare, an expert in control systems, is professor of chemical engineering at Lehigh.

The researchers' goal is to help Loya and others like him learn to use brain-computer interface (BCI) technology to regain control of functions they have lost due to brain damage or disease. They are focusing on the feedback mechanism that enables the cerebellum to correct for errors while executing extremely precise multijoint movements. Located at the base of the brain, the cerebellum contains more than half the brain's neurons (brain cells) but takes up only 10 percent of its volume. It integrates sensory perception, coordination and motor control, and signals the cortex, the outermost layer of the brain, to command muscles to move.



Scientists and engineers have developed BCIs that signal actuators to move cursors and operate artificial hands and other neuroprosthetic devices. Thakor's lab has helped transradial (below-the-elbow) amputees control prosthetic hands that are linked to the signals generated by the muscles on their residual limbs. In another project, his group decodes brain signals to command prosthetic hands to open and close.

But little research has been done to enable BCIs and neuroprostheses to respond as the cerebellum does to sensory feedback from the environment. A driver changing lanes on the highway and an outfielder chasing a fly ball must adjust to changes in the environment and in their perception of the environment. Similarly, as a hand reaches for a cup, "force feedback" from the hand and visual feedback from the eye tell the cerebellum how much farther and in what direction the hand must move to complete its task. The cerebellum processes this feedback and sends new signals ordering the hand to take corrective action.

It is this feedback process that the Lehigh–John Hopkins team is seeking to interpret and to model mathematically. "Force, visual and all other kinds of feedback influence how the brain changes its signals," says Kothare. "We want to interpret these modified signals and convert them into action. "To do that, we have to understand the entire closed loop. This includes the brain signals, the interpretation of the signals, the implementation of the brain's command, the feedback by sensors to the brain, and the transmission of new brain signals that are modified in response to the environment. We want to measure and model this entire system."

THREE-WAY SERENDIPITY

The idea for the Lehigh-Johns Hopkins collaboration originated when Kothare and Thakor met at a reunion of alumni from the India Institute of Technology and discovered a common interest in neuroengineering.

"I have always been interested in control theory and feedback and its impact on learning," says Kothare, who previously engineered a chip-based microreactor that catalyzes methanol into hydrogen and also investigated an implantable device for insulin delivery.

In 2008, Kothare and Thakor became one of about 30 teams out of 1,250 competing to win a grant through NSF's Cyber-Enabled Discovery and Innovation (CDI) initiative. The three-year award has partially supported Kothare's sabbatical at Johns Hopkins' School of Medicine.

Two months into the project, Kothare met Ying when she proposed a project using BCIs to study ataxia patients and other persons with cerebellar defects. Ying secured approval to do studies on actual subjects, while Kothare obtained certification from the Johns Hopkins Institute Review Board. Thakor, who is an investigator for DARPA's Revolutionizing Prosthesis Program, already had a lab set up for BCI research and EEG monitoring.

Kothare then recruited Geoffrey Newman, a graduate student in biomedical engineering at Johns Hopkins, and Youngseok Choi, a postdoctoral neuroengineer who develops neurological signal analysis methods for brain injuries. Choi, a visiting researcher at Johns Hopkins, now oversees signal processing for the ataxia project. Newman has helped modify a previously developed BCI hardware-software platform and equip it with an interface that runs the cursor-target experiments.

PROFOUND AND LIFE-ALTERING

Ataxia comes from two Greek words – a, meaning without, and taxis, meaning order. An estimated 150,000 Americans suffer from the condition, according to the National Ataxia Foundation, and they include men and women, young and old, and members of every racial and ethnic group.

Often hereditary, ataxia is a set of symptoms that result from disease, defects or damage to the cerebellum. It afflicts fingers, hands, legs, balance, speech and eye movements, and it is degenerative. From slurred speech and unsteady balance, patients typically progress to the point at which the simplest tasks require the utmost will power.

Many types of ataxia, including Loya's, do not shorten a person's life, says Ying, who has worked a decade with ataxia patients. But ataxia in all its forms alters life profoundly.

"Ataxia is socially very isolating. Ataxia patients can't speak well and they can't move around. They spend a lot of time on the Internet, but may have difficulty typing."

BCI technology promises to restore some social life by helping ataxia patients perform activities that can be interfaced with a computer, says Ying. These could include operating a wheelchair or using prosthetic limbs. But scientists must first improve their ability to interpret and harness brain signals.

That endeavor is daunting. The brain's 100 billion cells make thousands of connections with each other every second. To probe this activity with 64 electrodes, says Thakor, is like asking space aliens who know nothing of human beings to observe the earth and summarize all of its intelligent life from 64 orbiting satellites.

But electrodes placed on the functioning part of the sensory and motor cortex would allow scientists to capture the cortical signature, says Thakor. Humans could then learn to control the signals in this region of the brain by modulating the frequency of those signals, much as a soprano renders an aria by modulating the pitch of her voice.

One question yet to be answered, says Ying, is whether ataxia patients can control their brain signals as well as normal people. Can they perform as well on the cursor-target exercise and other brain signal tests? Ying is correlating those test results with MRI scans to determine if anatomical clues might predict the ability of Loya and other ataxia patients to master BCI technology.

The research team is also planning a set of experiments to measure the impact of feedback on the transmission of brain signals. The team will implant electrodes on the cortices of epilepsy patients undergoing surgery for seizures. The electrodes will enable the researchers to obtain a "neural signature" by recording the brain signals that are generated when a postsurgery patient performs a routine task. The goal is to observe how that signature changes with and without visual feedback.

"We will ask the person to close his eyes and reach for an object," says Kothare. "Without the benefit of visual feedback, the person will have to rely on force feedback, along with the memory of the position of the object, to accomplish the task. Then we will tell the person to open his eyes and reach for the object. We will watch the progress of the person's arm toward the object while we measure the neural signals being emitted.

"Our hypothesis is that the signals generated by the brain during each of these scenarios will be different. This hypothesis has never been tested in an experiment. We hope to understand how neural signals change as feedback occurs."

"ANY WAY I CAN"

Back in Johns Hopkins' neuroengineering lab, Roy Loya has completed the two-hour brain signal exam. After seven years of MRIs, movement studies, gait testing and cognitive exams, this has been Loya's first trial with BCI technology. In addition to the cursor-target test, he has also attempted to modulate his brain waves by thinking calm or agitated thoughts. The day has been a qualified success. Loya did well for an hour, then tired. And the researchers need to work on the signal-processing software and refine an algorithm to achieve a better balance between left and right hand.

Tax lawyer, pilot and engineer, Roy Loya says he will do whatever he can to help researchers improve brain-computer interfaces.

Loya's handshake is firm as he says good-bye to the researchers, and his face is alert. He begins to reminisce, moving his hands alongside his neck to improve control over his vocal cords. His words rumble out, each the product of great effort. But he makes himself understood.

As a young man, Loya completed a bachelor's degree in aeronautical engineering from Princeton. He went to law school at the University of Maryland and at Georgetown. He practiced tax law for 20 years and traveled to 70 countries on six continents. He earned a pilot's license and flew the Douglas DC-3, a propeller-driven transport plane used in World War II.

Loya did not notice his first symptom of ataxia until eight years ago, when air-traffic controllers began having trouble understanding his speech. Now he has one goal.

"I have always loved science. I want to help these people any way I can."

 PHOTOGRAPHY BY DOUGLAS BENEDICT

Corey Luthringer '09 studied the characteristics of wires that form from nanoparticles under an electric field.

A VALUABLE PROVING GROUND

Researchers sharpen their competitive edge in an annual undergraduate symposium

In five years, the David and Lorraine Freed Undergraduate Research Symposium has become a valuable proving ground for promising engineering students.

The event, held each spring in the P.C. Rossin College of Engineering and Applied Science, gives engineering students the chance to showcase their research. Students have just a few short minutes to express the significance of their work and answer questions from a team of judges that includes faculty and industry researchers.

More than 60 students have competed to date in the symposium, most as individuals and a few as pairs. Students spend about one year preparing their projects. Their work has covered almost every conceivable area of engineering, from crystal grain growth to virtual reality to optical technologies.

Corey Luthringer '09, a chemical engineering major, finished third in 2009 for a project titled "Microvascular Fabrication via Dielectrophoretic Assembly." Luthringer investigated how wires form from nanoparticles when exposed to an electric field gradient, and how the characteristics of these wires vary under different conditions. The goal is to use the wires to model such microvascular phenomena as the formation and propagation of tumor tissues.

Taking part in the symposium, says Luthringer, helped her prepare for her new job in R&D at Schering-Plough, a pharmaceutical company in New Jersey.

"The symposium provided an environment for me to learn proper industrial and academic research methods, as well as a forum for sharing my findings with students, professors, staff and industrial visitors," says Luthringer. "It helped me learn how to explain my research to an audience using a variety of skill sets and technical knowledge."

"The symposium provided a forum for sharing my findings with students, professors, staff and industrial visitors."

– Corey Luthringer '09

Geoffrey Brunn '06, a structural engineering and architecture double major, took first place at the 2005 symposium. Now a structural engineering assistant in the San Francisco office of the Chicago-based international architectural and engineering firm of Skidmore, Owings & Merrill LLP (SOM), Brunn says his project involved studying a new form of precast concrete that flows like water, and proving that the material was cost-effective.

After graduating from Lehigh, Brunn earned a master's degree in structural engineering at UC Berkeley, then landed the job at SOM, where he designs tall buildings in the Middle East, China and other parts of the world.

"I'm constantly defending my ideas," he says, "so I draw on my experience from the symposium daily."

The symposium benefited both his resume and his self-confidence, says Brunn.

"Receiving the praise of established engineers, scientists and businessmen, for me, was a very valuable 'work hard and believe in yourself' lesson."

David Bell '07, a bioengineering major, won first prize in 2007 for a project titled "Finite Element Analysis of Clinical Pressure-Flow Wave Forms in the Eustachian Tube." Bell is now a Ph.D. candidate in the biomedical engineering program at the University of Utah, where he studies the mechanics of cerebral vasculature, particularly when blood vessels are exposed to explosions, accidents or other severe impacts.

Bell says the Freed award opened the door for him to present his work at ASME's Biomedical Conference in Colorado.

"That experience really boosted my confidence because I saw that there were people who cared about the work I do."

The award also helped him gain admission into some of the best graduate schools, including Johns Hopkins, says Bell.

"The Freed Symposium enabled me to do recognizable research that then was judged by a peer review panel. I think that stuck out on my resume."

Sean Kessler '08, a chemical engineering major, won first prize in 2008, his third and final year at Lehigh, for research into the timed release of Naproxen, an anti-inflammatory drug sold as Aleve.

One challenge in developing controlled-release medications, says Kessler, is to maintain a release rate that keeps drug levels in the body within the therapeutic range and avoids the "burst effect," in which a large and sometimes toxic amount of drug is emitted at one time.

Now an Energy Fellow and Ph.D. candidate in chemical engineering at MIT, Kessler studies atmospheric chemistry, specifically the sources and evolution of organic aerosols in the atmosphere.

With his funding from the Freed prize, Kessler will travel to the annual meeting of the American Institute of Chemical Engineers (AIChE) in November to give a talk on his project.

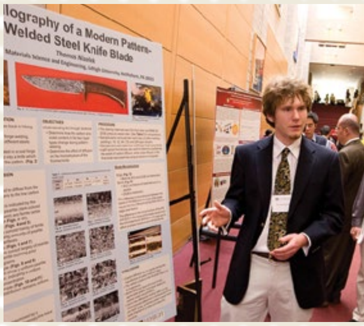
"The Freed Symposium experience taught me how to comport myself in presenting research work," says Kessler, "and how to articulate the most important aspects of my work to an audience that has varying levels of familiarity with the field."

A PROFESSIONAL ACT

Five years ago, Himanshu Jain and Wojciech Misiolek came up with a simple idea for changing Lehigh's research culture. Undergraduate students who want to do research, they proposed, should find out firsthand how to present their work to professionals in the field.

Jain and Misiolek, professors of materials science and engineering, organized Lehigh's first Engineering Undergraduate Research Symposium in 2005.

Twelve students competed at the symposium. Each prepared a poster and gave a 10-minute slide presentation to a panel of experts from academe and from companies such as Agere and Rohm & Haas.



Tom Nizolek '09 explains the ancient art of pattern-welded steelmaking.

The annual event is now called the David and Lorraine Freed Undergraduate Research Symposium, thanks to an endowment from Andrew D. Freed '83 in honor of his parents. Freed is a member of the engineering college's advisory board.

"We felt it was important to encourage more active participation by undergraduate students in the world of research," says Misiolek, "and to give them the opportunity to present and defend their work just as researchers and industry practitioners do."

"Lehigh's students are very good in the classroom," says Jain. "We wanted to help them deal with open-ended problems that are not in textbooks. We also wanted to raise the visibility of research on campus."

Students are nominated by their departments to compete in the symposium. They work with faculty advisers and learn to design an experiment, use lab equipment and solve problems that arise during the projects. Misiolek and Jain coach the students on presentation skills.

The presentations are judged by a panel of academic and industry researchers for creativity, significance to an engineering problem, visual quality of the poster, and ability of the student to defend the research. The top three students win travel stipends to attend professional conferences.

Nelson Tansu and Yik-Khoon Ee (below, in clean room) work in Lehigh's Center for Optical Technologies.

For best results, set the bar high

Even before they enroll, the students who come to Lehigh to study with Nelson Tansu know what will be expected of them.

Tansu, an associate professor of electrical and computer engineering, directs the MOCVD (Metalorganic Chemical Vapor Deposition) and Nanophotonics Group in Lehigh's Center for Optical Technologies (COT). His mission is to harness light from semiconductor nanostructures to achieve advances in energy, communications, biosensors and coherent sources.

His aspirations for his students and for his research program are the same.

"Our objective is to solve some of the most important challenges in engineering," he says, "by applying the fundamentals of physics. This requires rigorous research and academic training in multidisciplinary topics."

"We believe our new Ph.D.s are just as competitive as the doctoral graduates from any of the other top programs in the nation."

– Nelson Tansu

Sixteen graduate students and six postdoctoral fellows have worked in Tansu's group since he joined Lehigh's faculty in 2003, and the record suggests they are embracing his goal. The students publish highly cited articles in *Applied Physics Letters*, the *Journal of Applied Physics*, *Langmuir* and other leading refereed journals. Their work has been reported in *Compound Semiconductor*, *Laser Focus World* and other publications.

Earlier in 2009, *Illuminating Ideas: Innovations in Solid-State Lighting*, a publication of the U.S. Department of Energy, said Tansu's group had achieved one of the solid-state lighting technology highlights of the year by developing staggered InGaN quantum wells that improve the radiative efficiency of green light-emitting diodes (LEDs).

Several of Tansu's students have received patents and international prizes. Hongping Zhao has won a premier scholarship two years in a row from SPIE, the world's largest nonprofit professional society for optics, photonics and imaging. Yik-Khoon Ee won the Best Student Paper in nanophotonics at the IEEE Photonics Global Conference 2008, where his paper was chosen from among 96 submitted.

Tansu aims to recruit graduate students who possess three intangible qualities.

"We look for three things in students – motivation, persistence and high expectations for themselves. These can be hard to evaluate, because we don't have the funds to bring students in for personal visits. So I always interview candidates by phone to determine if they have the right mindset and focus."

At Lehigh, the new students, under the tutelage of Tansu and the senior graduate students, learn to apply the fundamentals of physics to the science and technology of semiconductor optoelectronics, semiconductor nanostructures and photonics.

"All of our Ph.D. candidates are required to master quantum mechanics, solid state physics, quantum electronics, photonics and lasers," says Tansu, "and to apply their knowledge to problems in nanostructure photonics materials and devices.

"We work intensively with the students to guide them in their research and academic studies. We try to create a tone and positive atmosphere that enable them to thrive."

Besides high-efficiency LED lighting, Tansu's group investigates solar photovoltaic cells, thermoelectric materials and devices, biological and chemical sensors, semiconductor lasers, and nitride-based semiconductors. The research is supported by DOE, NSF, DARPA, DOD and the state of Pennsylvania.

Tansu's students are trained to use and maintain the COT's extensive facilities, which include state-of-the-art MOCVD epitaxy reactors, etching tools, dielectric and metal evaporators, and light-resistant lithography equipment. This affords an advantage offered by few other university labs. In one building, students can perform all the steps – simulation, growing materials, advanced characterization, device fabrication and device testing – necessary to make a semiconductor photonics device.

The students put in long hours, but the rewards are worth it.

"Doctoral students typically publish one or two refereed journal articles prior to graduation," says Tansu. "We expect closer to 10, and most of our students meet or exceed that.

"When our Ph.D. students complete their studies at Lehigh, we believe they are just as competitive as the doctoral graduates from any of the other top programs in the nation, and just as prepared to make contributions to academe or industry."

The Fritz Legacy

2009 marks the centennial of Lehigh's Fritz Engineering Lab, a registered National Historic Engineering Landmark. From the Panama Canal, to the Golden Gate, Chesapeake Bay, George Washington, and (Niagara Falls) Rainbow Bridges, to city skylines all around the world and the first communications satellite to orbit above it, the influence of the lab – and the legendary Lehigh engineers who gave it life – is unquestionable.

NAE member and 2000 Fritz Medal recipient John W. Fisher regularly provides insight into high-profile structural failures, such as the 9/11 WTC attacks and the 2008 collapse of the I-35 bridge in Minnesota. As founding director of Lehigh's Center for Advanced Technology for Large Structural Systems (ATLSS), he helped sustain Fritz's Lehigh legacy in state-of-the-art infrastructural research and education.

As director of the Council on Tall Buildings and Urban Habitat, NAE member and professor Lynn Beedle was the recognized champion of skyscrapers as a viable alternative to urban sprawl, and inspired the world's architectural engineers to devise elegant solutions to problems of tall buildings and cities. Beedle won the Fritz Medal in 1995.

Some of the world's leading metallurgists and materials scientists – such as professors Robert Stout, Richard Hertzberg and NAE member Alan Pense – have engaged the lab's resources to better understand the interplay of materials and structural design.

NAE and Royal Society member George Irwin, along with fellow mechanical engineering professors Fazil Erdogan, George Sih and Robert Wei (left to right), helped launch Lehigh's international reputation in fracture mechanics. Their research enabled countless new ways of improving the safety and effectiveness of airplanes, bridges, buildings and other complex engineering systems.

A steel industry pioneer and original Lehigh Trustee, John Fritz (1822-1913) was world renowned as an inventor who "designed machinery almost incapable of breaking down." In 1905, the five major engineering societies of his day united to establish and bestow annually the John Fritz Medal, still considered the top award in the field of engineering.

In 1909, Fritz designed, funded and supervised construction of the outstanding engineering research resource of its time. Fritz Engineering Lab helped propel Lehigh into materials and structural research leadership, and contributed significantly to U.S. defense efforts in both World Wars. Overhauled in 1955, the Lab maintained its leadership status with the help of the Baldwin Universal Test Machine – which could crack an egg without harming its living contents, or produce 5,000,000 pounds of force to tear and crush 100-foot steel girders. The facility also provided for research and education in hydraulics, materials and concrete, soil mechanics, sanitary engineering, and structural modeling.

To learn more about the achievements of Lehigh engineers, visit the Lehigh Engineering Heritage Initiative at

www.lehigh.edu/heritage

LEHIGH UNIVERSITY

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A MASTER TOOLSMITH

User interfaces, says James D. Foley ’64, coauthor of “Fundamentals of Interactive Computer Graphics,” should be flexible and easy to repurpose. Foley, who founded the Graphics, Visualization and Usability Center at Georgia Tech, believes human-computer interaction is much more than a “soft” discipline.

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