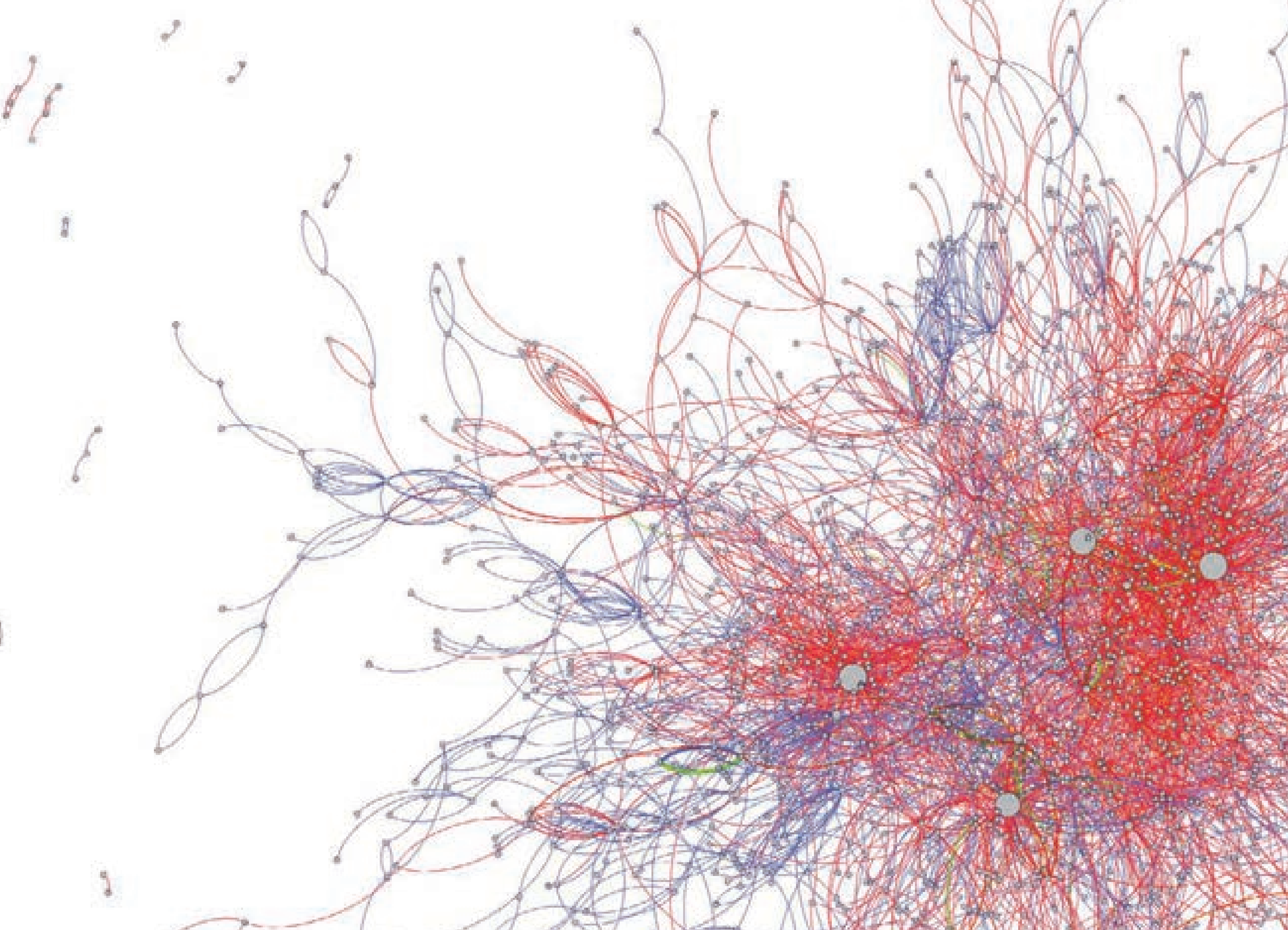
McCormick

magazine | fall 2012

Robert R. McCormick School of
Engineering and Applied Science
Northwestern University

THE DATA AGE

TURNING INFORMATION INTO INSIGHT



FROM THE DEAN

Greetings from McCormick.

We live in what many are calling the data age, and connectedness rules the world. Processing power and data storage are virtually free; a typical smartphone has computing power that puts a 1970s-era mainframe to shame. This ubiquitous computing power enables devices to gather data while we walk, while we shop, and while we drive. And, increasingly, devices can communicate with each other, forming what some have called the "Internet of things."

Yet having access to more data does not necessarily translate into more knowledge. We find ourselves in need of new approaches to help us find the insights and answers that are hidden in the flood of data.

At the very core, there are two ways of dealing with any challenge: rationality and intuition. As Albert Einstein said, "The intuitive mind is a sacred gift and the rational mind is a faithful servant." But the rational mind needs tools and crutches to help understand and evaluate situations, and the intuitive mind is honed by years of problem solving. Often we have neither the tools nor the experience to make sense of the unprecedented complexity and relentless change we face.

Our faculty are working on new methods, such as data mining techniques and analytics, that will allow us to bridge the rational and intuitive minds. In this issue you will read about ongoing research that seeks to make use of the power of data and the steps we are taking to educate tomorrow's leaders through our new Master of Science in Analytics program.

We also feature collaborations with the Rehabilitation Institute of Chicago, which was again voted the top rehabilitation hospital in America by *U.S. News & World Report.* In addition to partnering with McCormick on a multitude of collaborative research initiatives and faculty appointments, RIC provides design projects that allow our students to serve a real need in the marketplace.

In this issue we introduce the new Willens Engineering Life Sciences Wing, a six-story, 50,000-square-foot addition for the life and biomedical sciences. Made possible by a significant gift from Ronald and JoAnne Willens, the wing offers cutting-edge facilities—including offices, labs, and common space—in a modern design that integrates seamlessly with the original façade of the Technological Institute. The Willens Wing will be the permanent home for the Integrated Molecular Structure Education and Research Center, as well as many laboratories and office spaces for the nanotechnology, biomedical engineering, and mechanical engineering faculty.

I hope you will take some time to explore this magazine and our website (www.mccormick.northwestern.edu) to learn more about how we think and where we are going.

As always, I welcome your feedback.

Julio M. Ottino, Dean | November 2012

On the cover: A visualization of the network of teams that assembled to edit Wikipedia pages after the 2011 earthquake and tsunami in Japan. Image by Brian Keegan, a graduate student in the lab of Noshir Contractor. See "The Data Age," page 10.

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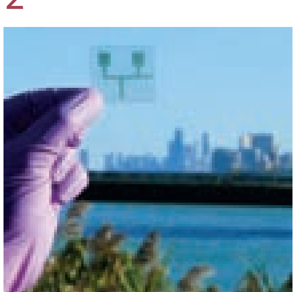

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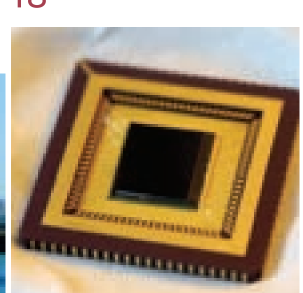

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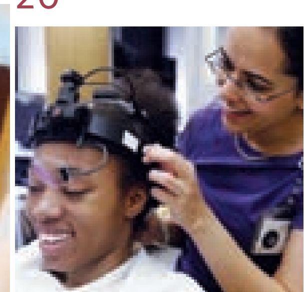

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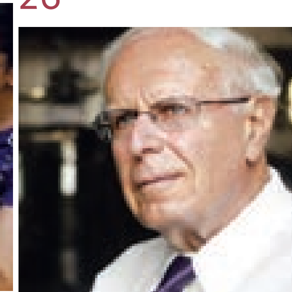

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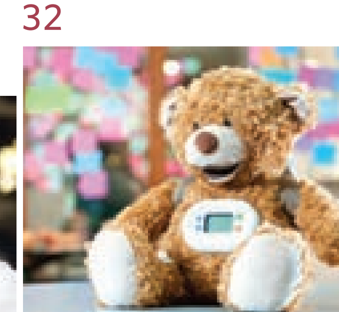

McCormick news

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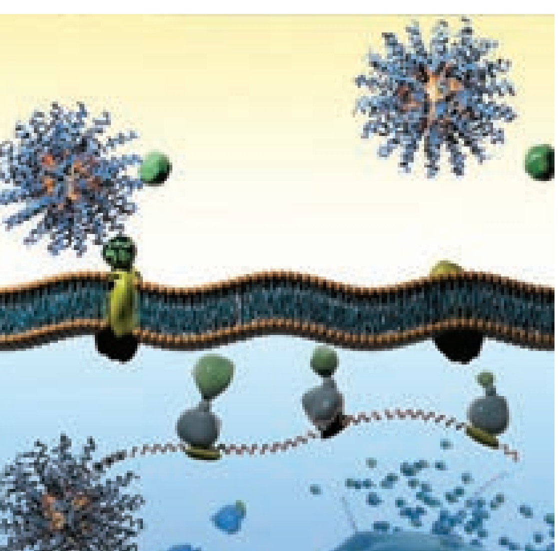
BREAKING THE SKIN BARRIER

Recent research by a team led by the McCormick School's **Chad Mirkin** and a dermatologist from the Feinberg School of Medicine gives "getting under your skin" new meaning. The team is the first to demonstrate the use of commercial moisturizers to deliver gene-regulation technology potentially therapeutic for skin cancer.

The topical delivery of gene-regulation technology to cells deep in the skin is difficult because of the skin's formidable defenses. The Northwestern approach takes advantage of nanostructures consisting of novel spherical arrangements of nucleic acids that have the unique ability to traverse the skin and enter cells. They were developed in the lab of Mirkin, director of Northwestern's International Institute for Nanotechnology and George B. Rathmann Professor of Chemistry in the Weinberg College of Arts and Sciences, professor of medicine in the Feinberg School, and professor of chemical and biological engineering, biomedical engineering, and materials science and engineering in the McCormick School.



The nanostructure drug was designed to target epidermal growth factor receptor, a biomarker associated with a number of cancers. The researchers combined EGFR with a commercial moisturizer and applied the ointment to the skin of mice and to human epidermis. The drug penetrated the skin's layers and selectively turned off disease-causing genes while sparing normal genes. No adverse side effects were found after a month of continued application.

Early targets of the treatment are melanoma and squamous cell carcinoma; psoriasis; diabetic wounds; and epidermolytic ichthyosis, a rare genetic skin disorder for which there has been no effective treatment. Other applications could include combatting wrinkles.

Mirkin's coresearcher was Amy S. Paller, the Walter J. Hamlin Professor, chair of dermatology, and professor of pediatrics at the Feinberg School of Medicine and director of Northwestern's Skin Disease Research Center.

VOORHEES NAMED NORTHWESTERN-ARGONNE INSTITUTE CODIRECTOR

Peter W. Voorhees, the Frank C. Engelhart Professor of Materials Science and Engineering (top), and **Pete Beckman,** director of the Exascale Technology and Computing Institute at Argonne National Laboratory (bottom), have been appointed codirectors of the Northwestern-Argonne Institute for Science and Engineering.

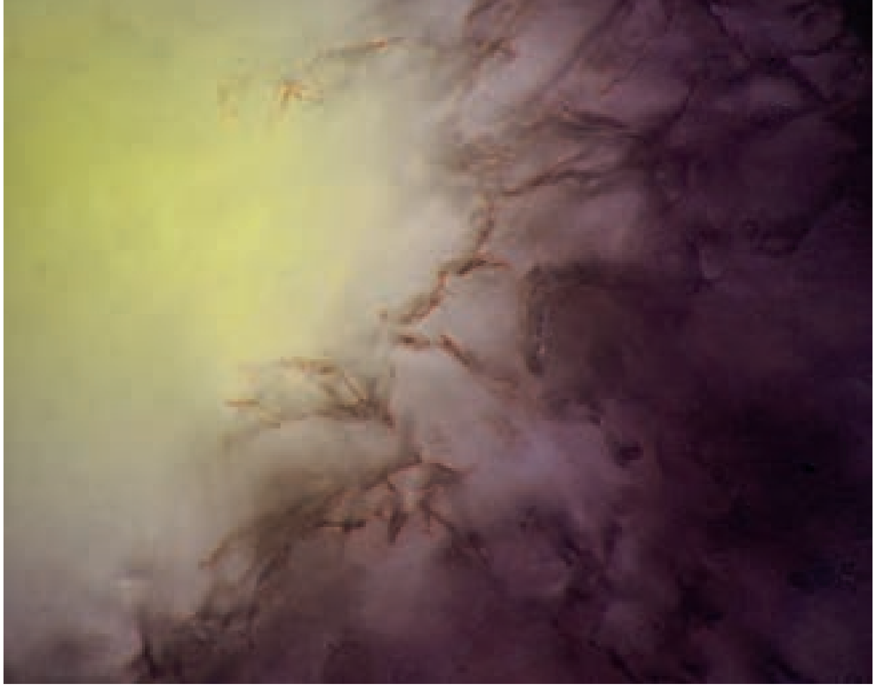
Established last year, the institute brings together Northwestern faculty and students and Argonne researchers to attack key problems in energy, nanoscience, and advanced scientific computing. A recent focus is on cutting-edge materials research to support President Obama's Materials Genome Initiative for Global Competitiveness. The institute is aiming to strengthen Chicago's innovation ecosystem by linking materials science experts and providing them with access to advanced tools.

Beckman and Voorhees will work together to enhance the experience of current Northwestern students, support and expand existing research programs and develop new ones, promote collaborations between Argonne and Northwestern, and streamline access to facilities.

NORTHWESTERN NSBE CHAPTER LAUDED

Northwestern's chapter of the National Society of Black Engineers has been recognized as the NSBE Region IV "Large Chapter of the Year" for its outstanding work in community outreach, academics, and professional development. Region IV includes Illinois, Wisconsin, Indiana, Michigan, and Ohio. "Large" chapters have at least 40 members.

The Northwestern chapter stood out for its effort in reestablishing a NSBE junior chapter at Evanston Township High School; its creation of the Engineering Interaction Fair for minority students ages 8 to 14; its weekly study halls for Northwestern students; mentorship programs; and other activities.



MCCORMICK STUDENT WINS SCIENTIFIC IMAGES CONTEST

For the second year in a row, Andrew Koltonow, a McCormick graduate student in materials science and engineering, has won first prize in Northwestern's Scientific Images Contest.

Presented by Science in Society, a University outreach initiative connecting science and the community, the contest recognizes research images that double as outstanding works of art. This year 12 winners from across Northwestern were recognized: five received top prizes and seven got honorable mentions. In all, seven winners were from McCormick.

Koltonow, who works in the labs of Jiaxing Huang, Morris E. Fine Junior Professor in Materials and Manufacturing, and Samuel I. Stupp, Board of Trustees Professor of Materials Science and Engineering, Chemistry, and Medicine, captured the winning entry while working with graphene oxide, an organic macromolecule that is only a couple of atoms thick but thousands of atoms wide (like a molecular-scale bedsheet). Koltonow and his colleagues assemble these atomically thin sheets into a solid, conductive foam with a high surface area. The foam can be used to create electrodes for batteries and supercapacitors, making such energy storage devices smaller and lighter. In this image, graphene oxide sheets (purple-orange) cast shadows from light that is scattered off the foam (green-yellow), creating an eerie effect.

SHEDDING LIGHT ON SOUTHPAWS

A McCormick professor and graduate student have used computer simulation to explain why only 10 percent of the human population is left-handed. The mathematical model developed by **Daniel M. Abrams,** assistant professor of engineering sciences and applied mathematics, and graduate student Mark J. Panaggio (both right-handers) shows that the low percentage of lefties is a result of the balance between cooperation and competition in human evolution. The researchers are the first to use real-world data (from competitive sports) to test and confirm the relationship between handedness and social behavior.

"The more social the animal—where cooperation is highly valued—the more the general population will trend toward one side," said Abrams. "The most important factor for an efficient society is a high degree of cooperation. In humans this has resulted in a right-handed majority."

If society were entirely cooperative, everyone would be same-handed, Abrams said. Abrams and Panaggio's model accurately predicts the percentage of left-handers in any group based on the degrees of cooperation and competition in the social interaction. Lefties are much more prevalent in the competitive world of sports than in the general population. More than 50 percent of elite baseball players are left-handed, as are well above 10 percent of athletes in boxing, hockey, fencing, and table tennis.

SPINTRONIC LOGIC DEVICES HOLD PROMISE FOR INCREASED COMPUTING POWER

Computers have just about reached their limit of power using complementary metal-oxide semiconductor (CMOS) technology in logic circuits. More powerful computers require more transistors; CMOS gives off more heat as transistors are added, causing a problem with heat dissipation. Engineers have been seeking an alternative, and McCormick researchers may have found it. They have developed a new logic circuit family based on magnetic semiconductor devices. The advance could lead to logic circuits up to a million times more powerful than today's.

"What we've developed is a 'spintronic' logic device that can be configured in a logic circuit that is capable of performing all the necessary Boolean logic and can be cascaded to develop sophisticated function units," said **Bruce W. Wessels,** Walter P. Murphy Professor of Materials Science and Engineering (top).

"Spin logic circuits" are created with the magnetoresistive bipolar spin transistors recently patented by McCormick researchers. Unlike traditional integrated circuits, which consist of a collection of miniature transistors operating on a single piece of semiconductor, spin logic circuits use the quantum physics phenomenon of electron spin. "Spintronic logic devices successfully perform the same operations as a conventional CMOS circuit but with fewer devices and more computing power," Wessels said.

While the breakthrough could take a decade to fully realize, "we think this is potentially groundbreaking," said graduate student Joseph Friedman, who worked on the research. Other Northwestern authors include **Gokhan Memik,** associate professor of electrical engineering and computer science, and **Alan Sahakian,** professor of electrical engineering and computer science (bottom).

NUVENTION: WEB COURSE FEATURED IN *CHICAGO TRIBUNE*

The *Chicago Tribune* covered the final spring 2012 presentations of NUvention: Web, the interdisciplinary course in which students design, build, and run software-based businesses in multidisciplinary teams. Students presented their concepts to the course's advisory board, which offered feedback on branding, growth prospects, customer acquisition strategies, and revenue models.

The June 7 story mentioned "Sartorial, an iPhone app that allows shoppers to snap photos of themselves and have their friends vote 'yes' or 'no' on the products in real time; Hungry Nephew, an online community for families to share and store cherished recipes; Petora, a site that connects dog owners with vetted dog boarders; and Stagecoach, a platform that members of the video production industry can use to organize projects."

For more on NUvention, see "A Tale of Three Companies" on page 32.

McCormick IN THE MEDIA

BUBBLE-FREE BOILING FEATURED BY SEVERAL OUTLETS

If you've seen water droplets skip across a hot skillet, you have observed the Leidenfrost effect. In 1756 German scientist Johann Leidenfrost observed that, over a certain temperature, a vapor cushion forms above a surface, allowing that dance of water droplets. **Neelesh Patankar,** professor of mechanical engineering, and collaborators around the world have used that long-known phenomenon to boil water without bubbles. The trick is a special coated surface that creates a stable vapor cushion between a surface and a hot liquid, eliminating the bubbles.

"It was really dramatic," Patankar told *Nature* about the discovery. The findings, which were also reported by *Scientific American*, *CBS News Tech*, and *NBC News Tech,* could help reduce damage to surfaces, prevent bubbling explosions, and enhance heat-transfer equipment.

NEW MERCURY DETECTOR REPORTED BY TWO MAGAZINES

When mercury is dumped into waterways, the toxic heavy metal can wind up in the fish we eat and the water we drink; even trace amounts can have long-term implications. In September both *Discovery News* and *R&D* magazine reported on a promising new detector from a Northwestern professor that may help avoid this danger.

A nanoparticle system developed by **Bartosz Grzybowski,** Kenneth Burgess Professor of Chemical and Biological Engineering, and collaborators in Switzerland can detect tiny amounts of mercury—more than 1 million times smaller than those detected by state-of-the-art current methods. The system is inexpensive and results are immediate. "With this system consumers would one day have the ability to test their home tap water for toxic metals," Grzybowski said.

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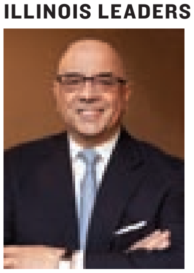
TINY HOUSE DISPLAYED AT MUSEUM

"Tiny House," a 128-square-foot, zero-net-energy house designed by Northwestern students and recent alumni, was on display at Chicago's Museum of Science and Industry for two weeks last spring.

Northwestern students were on hand to show off the house, which took two years to design and build. It can function completely off the grid and comes equipped with a living room, kitchen, bathroom, sleeping loft, storage area, fireplace, and awning for shade. The house produces its own electricity using solar panels and collects all of its water through a rainwater catchment system.

ILLINOIS LEADERS CONVENE AT INNOVATION ECONOMY CONFERENCE



More than 200 influential business leaders, academics, and scientists convened at Northwestern in June for "Building the Illinois Innovation Economy," a two-day National Academy of Sciences conference. Illinois governor Pat Quinn, a graduate of the Northwestern University School of Law, delivered the opening keynote. "If we don't invest in innovative opportunities, we'll never see them grow," Quinn told the audience. "Illinois is the middle of the country, the heart of the heartland … We have to embrace the people and the technology to make this happen."

Dean **Julio M. Ottino** spoke on the role of universities in the broader innovation ecosystem. He described how McCormick students learn both left-brain analytical thinking and right-brain creative thinking so that they can thrive at the intersection of many fields. He talked about students learning design thinking and doing interdisciplinary work through courses like NUvention.

The two-day meeting highlighted the state's innovation accomplishments and identified challenges faced by investigators, entrepreneurs, and universities.

NEW THERMOELECTRIC MATERIAL IS MOST EFFICIENT KNOWN

Chemists, physicists, material scientists, and mechanical engineers at Northwestern and Michigan State University have developed a thermoelectric material that is the best in the world at converting waste heat to electricity. The inefficiency of current thermoelectric materials (nearly two-thirds of energy input is lost as waste heat) has limited their commercial use. Now, with a very environmentally stable material that is expected to convert 15 to 20 percent of waste heat to useful electricity, thermoelectrics could see more widespread adoption by industry.

Possible areas of application include the automobile industry (much of gasoline's potential energy goes out a vehicle's tailpipe) and heavy manufacturing industries (such as refineries and power plants).

Developed by scientists including **Mercouri Kanatzidis,** Charles E. and Emma H. Morrison Professor of Chemistry, and **Vinayak Dravid,** Abraham Harris Professor of Materials Science and Engineering, the new material, based on the common semiconductor lead telluride, is the most efficient thermoelectric material known.

The efficiency of waste heat conversion in thermoelectrics is governed by its figure of merit, or ZT. This number represents a ratio of electrical conductivity and thermoelectric power in the numerator (which need to be high) and thermal conductivity in the denominator (which needs to be low). The new material exhibits a thermoelectric figure of merit of 2.2, the highest reported to date. The performance of the new material is nearly 30 percent more efficient than its predecessor. The researchers achieved this by scattering a wider spectrum of phonons across all wavelengths, which is important in reducing thermal conductivity.

MEDICAL STARTUP WINS TECHWEEK LAUNCH COMPETITION

BriteSeed, a startup developed by students in the NUvention: Medical Innovation course, won first place in the 2012 TechWeek Launch competition, walking away with more than $100,000 in cash and prizes.

Thirty-five progressive startups competed in TechWeek Launch, held during a June technology conference at Chicago's Merchandise Mart.

BriteSeed's product, SafeSnips, can be integrated into surgical tools to detect blood vessels and prevent unintended bleeding during surgery. The device was created during the 2011–12 academic year by a team of four students representing three Northwestern schools: Mayank Vijayvergia (far left) of the McCormick School, Paul Fehrenbacher (third from left) of the Feinberg School of Medicine, and Muneeb Bokhari (far right) and Jonathan Gunn (second from left) of the School of Law.

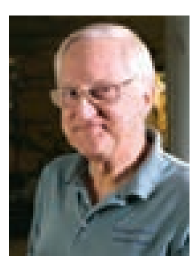
BriteSeed's prizes included Microsoft software and hardware products; payroll, benefit, and risk management administration services; business consulting; legal services and consultation; and IT planning, design services, and development.

MCCORMICK FACULTY AWARDS

Monica Olvera de la Cruz, who is known for developing theoretical models to determine the thermodynamics, statistics, and dynamics of macromolecules in complex environments, has been elected to the National Academy of Sciences.

Olvera de la Cruz is the Lawyer Taylor Professor of Materials Science and Engineering in the McCormick School, professor of chemistry in the Weinberg College of Arts and Sciences, and director of the Materials Research Science and Engineering Center.

Membership in the NAS is one of the highest honors given in the United States to a scientist. Olvera de la Cruz is among 84 new members and 21 new foreign associates. She is also chair of the National Research Council's Condensed Matter and Materials Research Committee and Board of Physics and Astronomy and a fellow of the American Academy of Arts and Sciences, the American Physical Society, and the US Department of Defense's National Security Science and Engineering Faculty Fellowship program. She received the NAS's 2007 Cozzarelli Prize for a scientific paper.



Gregory B. Olson, Walter P. Murphy Professor of Materials Science and Engineering, has been elected to the American Academy of Arts and Sciences. He is in a group of 220 new members, including eight others from Northwestern.

A designer of high-performance alloys, Olson is considered a founder of computational materials design. He directs the Materials Technology Laboratory/Steel Research Group at McCormick. Olson developed a systematic science-based approach for designing structural materials that calculates the optimum composition and processing route of desired properties.

Olson is also a member of the National Academy of Engineering. He founded a materials design company, QuesTek Innovations, whose first creation was a high-performance steel for gears. It was designed at Northwestern and licensed to the company. QuesTek developed the first fully computationally designed flight-qualified material, the Ferrium S53 steel aircraft landing gear.

Wing Kam Liu, Walter P. Murphy Professor of Mechanical Engineering, has received the 2012 Gauss-Newton Medal, the highest award given by the International Association for Computational Mechanics.

Liu is founding director of the National Science Foundation Summer Institute on Nanomechanics and Materials, founding chair of the American Society of Mechanical Engineers' NanoEngineering Council, and cofounding director of Northwestern's Predictive Science and Engineering Design Program.

A world leader in multiscale simulation-based engineering and science, Liu has applied atomistic, quantum, and continuum strategies toward the understanding and design of nanomaterials, biological processes, and use of organic and inorganic materials for drug delivery devices, biosensing, and other diagnostic and therapeutic applications.

Liu is Northwestern's second winner of the Gauss-Newton Medal. **Ted Belytschko,** Walter P. Murphy Professor and McCormick Professor of Mechanical Engineering, won the award in 2002.

Jorge Nocedal, professor of industrial engineering and management sciences and director of McCormick's Optimization Center, has been awarded the 2012 Dantzig Prize for original research that has had a major impact in mathematical optimization. The prize is awarded every three years by the Mathematical Optimization Society and the Society for Industrial and Applied Mathematics.

Nocedal has made fundamental contributions to the theory of nonlinear optimization methods and has created new algorithms for a variety of applications. His nonlinear optimization software, KNITRO, is used in the energy, computer, and financial industries to optimize everything from the design of computer chips to the production and delivery of electricity.

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CROSS-DISCIPLINARY GROUP PRESENTS PROFESSIONAL THEATER AT TECH

Think the arts are just on South Campus? Think again. For three weeks this fall the Technological Institute's Jerome B. Cohen Commons dining area was transformed into a 90-seat black box theater for *The How and the Why,* a drama by playwright Sarah Treem that examines how passion for science can set up unexpected rivalries.

The two-woman show was the fifth production of ETOPiA: Engineering Transdisciplinary Outreach Project in the Arts, a McCormick outreach initiative funded in part by the National Science Foundation. ETOPiA's goal: to use theater to inspire cross-disciplinary dialogue about the role of science and technology in society. To that end, each performance was followed by a talkback session with Northwestern faculty and students. And with the talents of award-winning actors and directors, the production value is high. "Our annual performances at Tech have earned a solid reputation among professional performers and directors in the Chicago area," said Matthew Grayson, associate professor of electrical engineering and computer science at McCormick and ETOPiA's producer.

TWO PROJECTS RECEIVE GLOBAL HEALTH RESEARCH GRANTS

Innovative research in synthetic biology by three Northwestern professors has been recognized with two early-stage discovery awards from Grand Challenges Explorations, an initiative funded by the Bill & Melinda Gates Foundation. GCE awards support unconventional research that has promise to improve health in the developing world.

Each of Northwestern's two projects will receive an 18-month grant of $100,000. Successful projects will have an opportunity for a second grant of up to $1 million.

Keith Tyo, assistant professor of chemical and biological engineering (top), and **Andreas Matouschek,** professor of molecular biosciences in the Weinberg College of Arts and Sciences, will develop synthetic compounds that could lead to new treatments for malaria. They are researching the potential destruction of *Plasmodium,* the parasite responsible for malaria, by its own protein degradation mechanisms.

In the other project, Tyo and **Joshua Leonard,** assistant professor of chemical and biological engineering (left), will work to engineer yeast-based biosensors that identify protein biomarkers in substances such as blood and urine. These biosensors could be used in low-cost in-home diagnostic devices by patients in resource-poor settings.

MCCORMICK RANKS HIGH AMONG ENGINEERING SCHOOLS

McCormick ranks 16th in the world and 10th in the United States among engineering schools, according to the Times Higher Education World University Rankings released this fall. Among universities Northwestern ranked 19th worldwide and 14th nationwide.

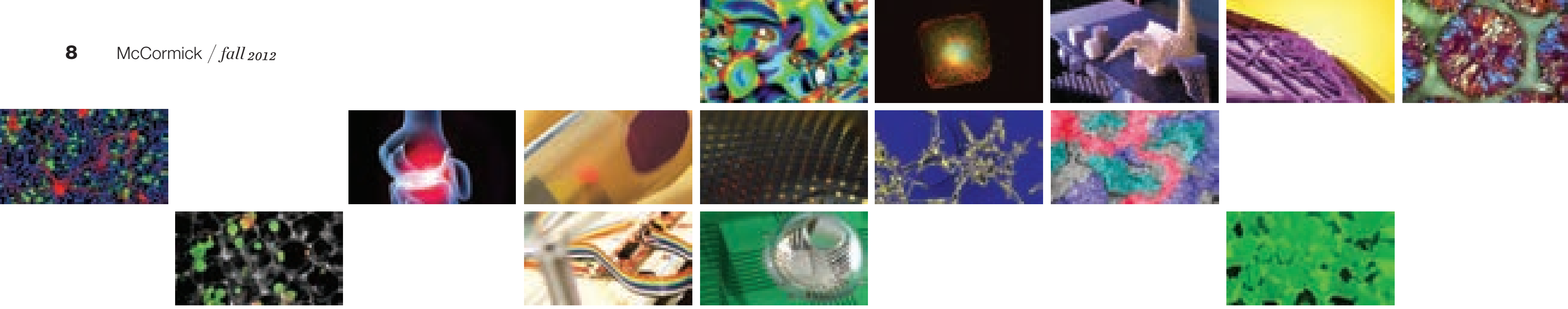
Powered by Thomson Reuters, the rankings judge universities across all of their core missions, including teaching, research, knowledge transfer, and international outlook. The rankings employ 13 performance indicators to provide comprehensive and balanced comparisons.

GIFT FUNDS REGENERATIVE NANOMEDICINE CENTER

A center that will enhance Northwestern's global leadership in regenerative nanomedicine will be established with a $10 million gift from the Querrey Simpson Charitable Foundation. The Louis A. Simpson and Kimberly K. Querrey Center for Regenerative Nanomedicine, named for a 1958 alumnus of Weinberg College and Northwestern trustee and his wife, will operate within the Institute for BioNanotechnology in Medicine (IBNAM).

The nanomedicine research it will support will employ designed nanostructures in an attempt to create novel therapies to treat disease and trauma, discover avenues to regenerate bodily tissues and organs, develop innovative diagnostic devices, and improve understanding of biological systems.

The research of IBNAM director Samuel I. Stupp, clinical faculty, and students over the last decade shows great promise for regeneration of tissues. Some of Stupp's novel materials promote regeneration in the central nervous system, which could affect therapies for spinal cord injury, stroke, Parkinson's disease, Alzheimer's disease, and other neurodegenerative diseases. Other work has focused on regeneration of cartilage, bone, and heart tissue; growth of new arteries; and diabetes treatments.



stories from the intersection

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Energy and environment

Investment tax credit recommended to spur wind power

The State of Illinois is facing an important renewable energy deadline in 2025. Harold H. Kung, professor of chemical and biological engineering, has advice for state officials to consider now: investment tax credit.

Illinois is obligated to begin increasing its production of electricity from renewable sources, a significant chunk of which will be wind power. Wind farms are expensive to build, resulting in higher energy costs for consumers and some risk to the investors needed to stimulate wind farm development. Government tax incentives can help address these issues.

Kung analyzed the impact of two incentives—investment tax credit and production tax credit—in six wind farm scenarios and found the former to be more attractive for both consumers and investors. It would provide a lower cost to consumers for electricity produced from wind and a faster return on investment for investors. Kung added, however, that the benefit of investment tax credit disappears when the capital cost is fully depreciated, whereas a production tax credit could continue for as long as the policy permits.

Health and wellness

Biocompatible electronics vanish when no longer needed

A team of researchers from Northwestern University, the University of Illinois at Urbana-Champaign, and Tufts University has demonstrated biocompatible "transient" electronics that gradually disappear on a specified schedule.

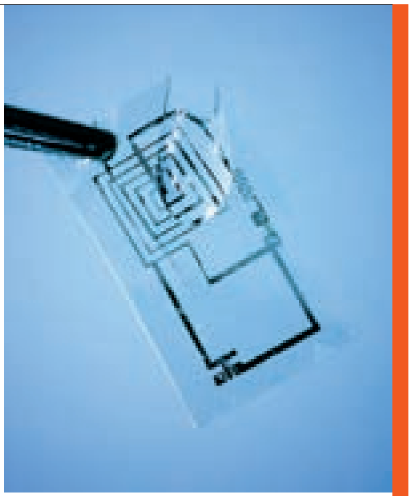
"This is a completely new concept," said Yonggang Huang, Joseph Cummings Professor of Civil and Environmental Engineering and Mechanical Engineering, who led the Northwestern research team.

The novel technology opens up the possibility of medical devices implanted inside the human body to monitor functions such as brain activity or to deliver drugs. When no longer needed, the electronics would be fully absorbed by the body with no adverse effects.

The system is made up of the electronics encapsulated by layers composed of magnesium oxide covered with silk. The encapsulation layers dissolve first and dictate the first dissolution timescale; the magnesium electrodes in the electronics define the second timescale.

John Rogers, of the University of Illinois, led the combined multidisciplinary research team and the U. of I. group that worked on the experimental and fabrication work of the transient electronics. Huang and his Northwestern team developed a model that can accurately predict how thick the encapsulation layers need to be for a specific dissolution time. The model was tested against experimental evidence, and the two agreed each time.

The researchers demonstrated that the transient electronics, including heater, sensor, and power supply, can operate in both water and a phosphate-buffered saline liquid. (PBS is chemically very similar to fluids in the human body.) Induction coils provide a wireless power supply to the electronics.

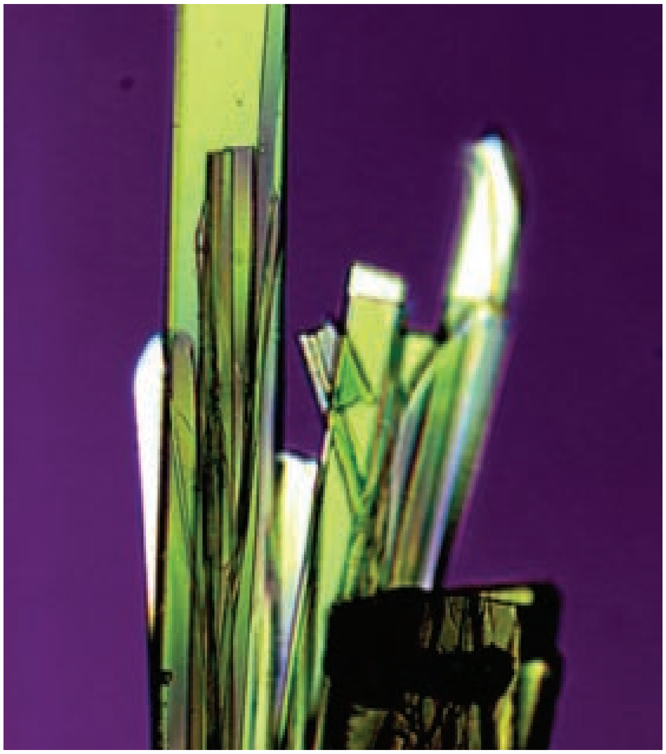


"This way the devices in water or PBS liquid can have power without being physically connected to a power source," Huang said.

The research was published in September in the journal *Science*.

Materials

New crystals could cut cloud computing cost



A new class of organic materials developed at Northwestern boasts ferroelectric properties that might be used to bring down the cost of cloud computing. The crystalline materials also have a great memory and are simple and inexpensive, enhancing their attractiveness for computer and cellphone memory applications.

A team of Northwestern organic chemists discovered that they could create long crystals with just two small organic molecules whose strong attraction causes them to self-assemble into an ordered network, which is needed for ferroelectricity. Ferroelectric materials exhibit spontaneous electric polarization (one side of the material is positive and the opposite side negative) that can be reversed by the application of an electric field (from a battery, for example). These two possible orientations make the materials attractive to computer memory researchers because computer memory stores information in ones and zeros, and one orientation could correspond to a one and the other to a zero.

Currently, cloud computing is expensive because electric power has to be kept on to retain information. The new ferroelectric materials could be developed with nonvolatile memory to retain information when power is turned off. If the cloud and electronic devices were to operate on nonvolatile memory, $6 billion in electricity costs would be saved in the United States annually.

"This work will serve as a guide for designing these materials and using ferroelectricity in new ways," said Samuel I. Stupp, Board of Trustees Professor of Chemistry, Materials Science and Engineering, and Medicine and member of the research team. The results were published in *Nature* in August.

Creating leaders

McCormick students honored at conference

Two McCormick graduate students received honors in August at the National GEM Consortium conference, which promotes the participation of underrepresented groups in postgraduate science and engineering education. Northwestern was the only school with two finalists among the six in the technical presentations.

Joshua Lawrence (second from left), a master's student in electrical engineering and computer science, was named GEM fellow of the year, the top prize among nearly 100 GEM fellows. Lawrence also won first prize in the MS division for his technical presentation.

Jovanca Smith (second from right), a PhD student in civil and environmental engineering, won second place in the PhD Division for her technical presentation.

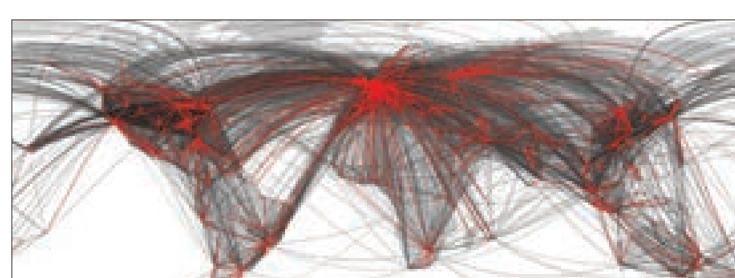
GEM fellows are offered stipends, paid tuition, and internships with GEM employers. The annual conference is an opportunity for these fellows to network and present their internship research to the GEM membership.

Systems

Complex networks have similar skeletons

Northwestern researchers have discovered that very different complex networks—ranging from global air traffic to neural networks—share very similar backbones. By stripping each network down to its essential nodes and links, they have found that each network possesses a skeleton and that these skeletons share common features, much like vertebrates do.

The surprising discovery that networks all have skeletons and that they are similar was published by the journal *Nature Communications.* The researchers studied a variety of biological, technological, and social networks and found that all of them have evolved according to basic growth mechanisms. The findings could be particularly useful in understanding how anything—a disease, a rumor, or information—spreads across a network.



"Infectious diseases such as H1N1 and SARS spread in a similar way, and it turns out [each] network's skeleton played an important role in shaping the global spread," said Dirk Brockmann, associate professor of engineering sciences and applied mathematics. "Now, with this new understanding and by looking at the skeleton, we should be able to use this knowledge in the future to predict how a new outbreak might spread." (For more, see "Models in the fight against disease," page 13.)

The Data Age

Researchers mine masses of data for new solutions and understanding

When they look back at this age, historians may comment that the currency of choice—what we manufactured and traded in—was, for the first time, information. The amount of data created each year requires using terms that the layperson can't fathom. One study puts annual data creation and replication at 1.8 zettabytes—equal to 1 billion terabytes. (Today's average home computer hard drive averages anywhere from 500 gigabytes to 1 terabyte.)

What's unique about this currency is that it doesn't age, doesn't degrade, and can self-replicate infinitely. We've figured out how to store it; anyone with a few hundred dollars can buy a few terabytes of hard drive. But as information accumulates, we lack the time and the capacity to search through it, so it becomes less and less valuable. How can we use it to find not only the answers we seek but also insights we never imagined?

Illustration: Mark Allen Miller

The answer is data mining and analytics—designing models and algorithms that can parse through terabytes and petabytes of data to find the gems leading to new solutions and understandings in fields as varied as business, medicine, and science. Several McCormick professors are at the forefront of mining large data sets and are teaching the next generation a set of skills that could make them extremely valuable in the workplace.

"I'm getting calls from firms that see the value in big data, but they don't know how to extract it," says analytics expert Diego Klabjan, professor of industrial engineering and management sciences. "It's definitely a very, very hot area. Everyone's looking for expertise. We've had tremendous interest from companies. These days every company needs analytics. They need to hire a workforce that is capable of analyzing data."

To that end, McCormick recently developed a master of science program in analytics. The inaugural class of the 15-month program is learning data warehousing techniques, the science behind analytics, and the business aspects of analytics. Directed by Klabjan, the program has its own computing cluster to take on big-data problems, and students will each do a summer internship. They will learn to identify patterns and trends, interpret and gain insights from vast quantities of structured and unstructured data, and communicate their findings in business terms.

"Our students will be hired by excellent companies," Klabjan says.

Giving computers the data to solve great problems

While industry is getting on board, Doug Downey has already spent years thinking about big data and its possibilities. "I've always seen it as an important challenge and a key enabler," says the assistant professor of electrical engineering and computer science.

When Downey arrived at McCormick in 2008, he decided to use data as a resource to take another tack with a huge engineering challenge: artificial intelligence.

"I thought that there are huge amounts of data that could make artificial intelligence problems we considered really hard in fact really easy," he says. Researchers might eventually teach computers to solve the world's greatest problems—such as curing cancer. Downey began his research by building systems that can automatically extract information from web data. With graduate student Brent Hecht, he designed an "exploratory search" program called Atlasify, a visual search engine that combines cartography with web mining to provide a graphic tool to explore concepts and correlations. To make the program user-ready has taken months of work. The researchers had to build software tools that can determine correlations between information on disparate Wikipedia pages, and they had to make the system quick enough to respond to queries in real time.

"This gives users a way to automatically tie together a bunch of very different sources of information and come up with insights that could help them understand concepts," Downey says.

Atlasify can provide maps and charts with any sort of reference system, from the relatedness of Elvis Presley and Russia to the correlation of rock and hip-hop based on Grammy Award winners. A concept such as nuclear power, for instance, is visualized with a world map of nuclear capabilities and a US Senate floor map showing senators' support for nuclear power legislation.

Downey hopes such tools as Atlasify ultimately do more than just satisfy a single user's thirst for knowledge. "It could make human life phenomenally better," he says. "When you get a ton of data, it changes the kinds of problems you can solve. That's what I get most excited about."

Left to right: Doug Downey, Dirk Brockmann, Noshir Contractor

Models in the fight against disease

While Dirk Brockmann's computations aren't yet curing diseases, they are making headway into learning how diseases spread. Brockmann's research group is building models from large data sets on human mobility and on past outbreaks of disease.

"We want to eventually be able to predict the spread of emerging infectious disease—just like forecasting the weather," says the associate professor of engineering sciences and applied mathematics.

Brockmann's group found that complex networks—from disease outbreaks to global air traffic—share similar backbones. By stripping each network down to its essential nodes and links, the researchers found that each possesses a skeleton and that the skeletons have common features. This reduction of complexity should make it easier to predict the spread of pandemics, Brockmann says.

Now the group is inverting its network theory techniques to remap the enterohemorrhagic *E. coli* (EHEC) outbreak in Europe last year to determine the geographic source of the epidemic. "It's a new idea to turn the problem around and ask not where the disease spread but where it first began," Brockmann says. "This has never been done before."

Brockmann is also using his network techniques to determine the important links in cancer gene networks. Using large data sets of a human's 23,000 genes and how they are expressed in cancer, Brockmann, working with professor of engineering sciences and applied mathematics Bill Kath, hopes to whittle that network down to the most important nodes and links. "Which connections are really important?" he says. "We hope to narrow it down so the experimentalists can focus on malfunctioning areas."

This sort of network research could have implications in other academic realms, too. Brockmann hopes to use the same techniques to determine the origin of farming technology during the Neolithic period.

"There's a big discussion of how farming spread into central Europe and replaced the hunter-gatherer mode of life," he says. "We could use our network techniques with archaeologists' large data sets of sites to determine the origin of this culture."

Brockmann's research attracts undergraduates eager to delve into big data; even though they cannot recall a time before the Internet, they are still fascinated with the magnitude of data available for research. Brockmann is fascinated as well, even after more than 10 years as a professor.

"I didn't know we would ever have access to this much data," he says. "That makes this field exciting, but it's also a challenge. You have to evolve quickly to be able to devise models that can deal with this amount of data."

From big data to broad data

For Noshir Contractor, mashing data sets together is the future of data research.

"What is really exciting is 'broad data': getting data from different sources and being able to combine them to find new insights," says Contractor, the Jane S. and William White Professor of Behavioral Science, who has appointments in industrial engineering and management sciences, communication studies, and management and organizations. "That's much trickier than big data."

Contractor, known for using large-scale computing to test and develop social network theories, used his mashing skills to help the National Cancer

Left to right: Alok Choudhary, Diego Klabjan, Dan Apley

Institute develop its PopSciGrid Community Health Portal, which allows users to visualize and analyze data from disparate sources. For example, a user could mash together data sets of smokers and cigarette taxation in each state.

"It offers a new way to look at the data, to inspire discussion and analysis among a much larger community," Contractor says. "We're developing a tapestry of broad data rather than big data."

These days Contractor and his SONIC Lab (Science of Networks in Communities) are most interested in using broad data sets to determine how to best assemble teams. He's studying scientific teams—such as those supported by the Northwestern University Clinical and Translational Sciences (NUCATS) Institute at the intersection of basic, clinical, and translational sciences—and teams brought together to perform a specific task. Using a tailored computer war game where participants must work together to bring humanitarian aid to a certain site, Contractor's group is collecting data on each action and interaction to determine how players develop trust. Gamers are each assigned a task (such as looking for improvised explosive devices or making sure the convoy doesn't get blown up by insurgents) and must provide information to their teammates through voice or text chat. Researchers investigate how communication structures and trust affect team performance.

The gigabytes of server data created by each two-hour game allow the researchers to test hypotheses. "We've found that in some cases, having too much trust is not necessarily a good thing," Contractor says. "If people talk only to the few people they trust, their performance is worse."

Another new theory Contractor is developing regards the importance of studying ecosystems of teams. Previous team-theory studies focused on only the team at hand—not whether team members were involved with other teams within the ecosystem, which most people are. Contractor is focusing on how team performance is influenced by overlapping memberships with other teams in the ecosystem.

"We've never had the ability to study these things at scale," he says. "Previously social sciences have had to focus on doing small surveys or experiments. Now that we have big data at scale, we can look to make claims that we never could before with only a small sample."

Predicting extreme climate events

When it comes to weather, data at a large scale have been available for decades—we just didn't have the tools to mine them for insights.

Alok Choudhary, John G. Searle Professor of Electrical Engineering and Computer Science, is focusing on understanding climate change based on the wealth of observational weather data from the past 150 years. Data-mining techniques are allowing Choudhary and colleagues from five other universities to look for predictors of extreme events such as hurricanes and droughts. Current climate-change models work well for predicting big developments, such as global temperature change over the next 50 years, but not for predicting extreme events that result from climate change.

"With traditional data-mining techniques, it's like taking only a sample of the haystack to find the needle," Choudhary says. "We are designing new ways to analyze the entire haystack, to discover interesting and actionable information without having to ask specific questions."

For the past two decades Choudhary has used up to 50,000 processors to mine petabytes (about 1 million gigabytes) of data, searching for answers in climate change, social networks, astrophysics, and chemistry. A member of the International Exascale Software Project, which is working to design systems and hardware to process information more quickly, Choudhary developed algorithms to evolve with growing data sets.

Choudhary and his group are transforming weather data sets into climate networks in search of patterns that are predictive of events. The information could be helpful in deploying the right resources. "If you see humidity at a certain level for a few months in certain regions of Africa, then you can predict that there will be a meningitis outbreak," Choudhary says. "Then you can start to plan a vaccination."

Choudhary also uses data-mining algorithms that can identify and segment networks by what people say and whom they follow. The information could help companies target potential customers; for example, it might be that a person who is actively engaged with Amazon.com and likes University of Wisconsin football is a target customer for McDonald's. "It's a new way of thinking beyond broad-based demographics," Choudhary says.

Locating car-charging stations, research sites

Diego Klabjan, the electric car–driving professor of industrial engineering and management sciences, has extended his interest in sustainable energy to his large-data research: he has used analytics to create models of where to put electric car–charging stations. That involved culling information from several sources to find where and how people drive, where potential drivers of electric vehicles might live, and where these drivers might want to spend their time while their cars charge. Now Klabjan is analyzing data from the usage of charging stations to determine correlations with local demographics and economic activity.

Working with Irina Dolinskaya, Junior William A. Patterson Professor in Transportation and assistant professor of industrial engineering and management sciences, and a graduate student, Klabjan is also developing a smart routing system for electric vehicles. If an electric car driver doesn't have enough charge to get from A to B, the system will route him or her to a charging station. "Because the remaining [driving] range is affected by so many factors—outside temperature, inside temperature, how fast you accelerate—there are a lot of data to consider," he says. "It's a fascinating project from a practical and a research perspective."

Klabjan's other research took him all the way to Greenland to study the logistics of National Science Foundation research sites. He traveled on a military plane and spent days on the ice sheet that covers most of the country. Using a sophisticated logistics operations model, he hopes to find how many research sites the NSF should have over the next decade. "There's such a big variety of research projects that it is very challenging to estimate demand," he says.

The skills needed to keep up with the data

For years Dan Apley, associate professor of industrial engineering and management sciences, has performed statistical analyses for industrial quality control. In the past, data were often limited, sometimes coming from manual measurement of manufactured parts. When lasers began to do the measuring, Apley became a large-data researcher.

"Instead of employees taking a few measurements with calipers, or a machine taking dozens of measurements, a laser scanner can measure millions of points per part," he says. "There were suddenly huge amounts of data to help understand what's happening during the manufacturing process."

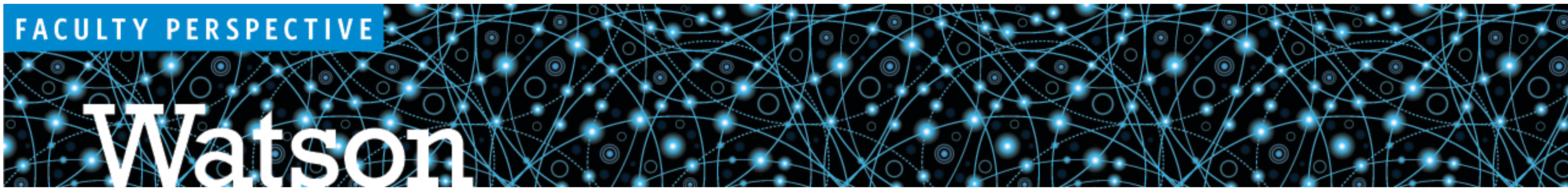
Apley later began using his skills in the service sector—most recently, analyzing customer data for a credit card company. The company's database contains thousands of variables (application and credit bureau data, monthly spending and payment data, etc.) for millions of customers. Apley was asked to narrow that information down to a small combination of variables that could best indicate whether the customer was high risk.

"To handle these large data sets—far larger than what people have looked at in the past—you need a broad skill set," he says. "You need to understand statistical modeling and computer science concepts and be able to code algorithms that are computationally feasible. And you must be able to interact with the domain experts to pick the brains of the people who know what problems are important, what solutions may be useful, and what variables may potentially contain relevant information. There is no magic-bullet data mining method that applies universally."

Apley plans to use his expertise in collaboration with materials science and other engineering professors to learn how microscale characteristics affect macroscale material properties and to discover new key microscale characteristics. They have recently submitted a number of proposals as part of President Obama's Materials Genome Initiative for Global Competitiveness, which seeks to build a national infrastructure for data sharing and analysis by scientists and engineers designing new materials.

"Years ago the limitation was the data, because methodologies for analyzing data had evolved faster than the structure of the data sets," Apley says. "Now the structure and availability of data—the size, the richness, the complexity—are advancing faster than the algorithms and methods of analysis that we have, and the data mining and statistical learning communities are challenged to keep pace." M Emily Ayshford

FACULTY PERSPECTIVE



Watson for Everyone

Faculty Perspective offers a space for McCormick professors to comment on issues facing their fields of research. In "Watson for Everyone," three computer science professors lay out how we can turn software from tool into collaborator.

The problems we face are growing ever more complex, but our human cognitive capacities remain unchanged. People and organizations are deluged with a rising tide of potentially relevant information, ranging from books, documents, and magazines to blog postings and tweets. Search technologies help, but even at their best, they provide only candidates, often far too many candidates, relying on people to do their own filtering and synthesis. What we need is systems that complement us, absorbing the tsunami of potentially relevant information, winnowing out the most relevant parts of it, and synthesizing material from multiple sources to produce actionable knowledge. These systems will embody a movement away from the traditional model of software as tool to a new model, software as collaborator, leading to a revolutionary impact of computing on all spheres of human life.

IBM's Watson provides a useful example. Watson's performance was revolutionary: it showed how a synergistic combination of artificial intelligence (AI) techniques could be used to perform fact-based question answering at a level that no one thought possible even a few years ago. (Fact-based question answering involves retrieving facts or combining facts in straightforward ways to select possible answers.) Watson used machine-reading techniques to assimilate vast collections of documents (more than 100 million pages) into internal representations that supported integration and reasoning. Machine-learning techniques helped Watson determine from experience which strategies were likely to succeed for different types of questions. Real-time response was provided by using massive hardware resources, capable of performing at the level of the best humans at its task.

Consider a Watson-like system applied to your documents, learning how to answer questions that matter to you. If you're a scientist, the documents would include the wide-ranging technical literature and potentially your laboratory notebooks, emails, and other records your organization maintains. If you're an intelligence or business analyst or a journalist, the documents would include a vast array of information sources, as well as detailed documents concerning particular subjects of interest. If you're a manager, the documents would include your organization's records and relevant news sources. If you're a teacher, they would include materials in the areas you teach, journals and forums describing the latest advances in techniques and practices, and school records. Even just fact-based question answering, if extremely accurate and fast, based on your documents and answering questions relevant to you, would be quite valuable. For that reason, we fully expect that a variety of Watson-like systems will be constructed by many organizations. It may seem like a daunting prospect because of the massive hardware required for Watson. Historically, however, once it is known that something can be done computationally, in many cases people find clever ways to do it with fewer resources. Deep Blue, after all, required what, for its time, was substantial parallel hardware, yet within a few years there were chess programs operating at almost its level of play while running on stock hardware.

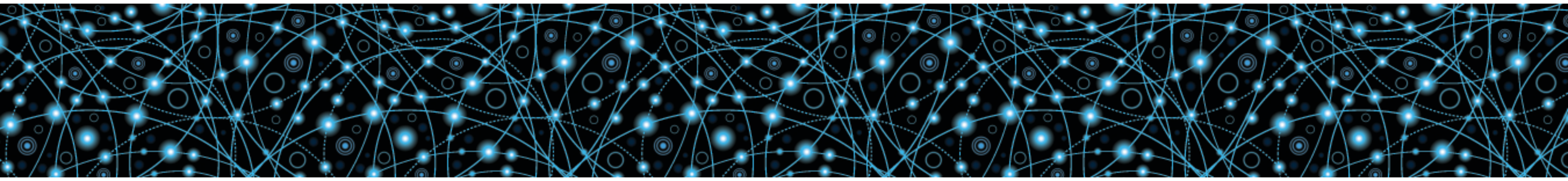
Such systems will be an initial step toward the software-as-collaborator model: the software is starting to adapt to your world, instead of you adapting to it. However, it would still lack many of the capabilities that we expect out of our human collaborators. Here are what we see as the core problems that must be solved to achieve our vision of software collaborators:

Reading for deeper understanding: Watson's reading processes can be viewed as a kind of skim reading, gathering factual material about entities and relationships in the world in order to answer questions by retrieving, and occasionally combining, facts about them. To answer deeper questions, material being read must be assimilated into coherent models. This remains an open problem; in fact, reading a textbook and answering its questions based on what was learned has been proposed as a grand challenge for artificial intelligence.

Many real-world problems involve tracking situations and problems over time. For example, keeping up with progress in areas of science and technology or unfolding political situations requires assimilating material being read into ongoing, accumulated conceptual models. This requires deeper reading than Watson used. Moreover, all of the sources given to Watson were reasonably authoritative (e.g., encyclopedias, the complete works of Shakespeare). Most of the time, though, our information sources contain more errors. And sometimes journalists, intelligence analysts, and business analysts must deal with dissembling and disinformation, as well as with the usual errors in sources. This means our software collaborators must help us distinguish fact from fiction.

Teachers, too, could benefit from software that can read and understand student work more deeply. Already natural-language techniques are being used to detect plagiarism and to score certain essay tests, but these rely on fairly crude statistical techniques. Being able to track which students exhibited particular misconceptions would provide a more fine-grained analysis of student progress, which could be used to tailor instruction (both inside and outside the classroom) more effectively.

Richer interaction: Software collaborators need better conversational skills. When interacting with people, Watson only took in questions as input, and each question was answered independently. Human conversation is far richer: we build up a shared context and shared models, ask follow-up and



clarification questions, and pose hypotheticals and alternatives. Our software collaborators need the same skills in order to maintain the shared state of conversations. This context includes both the immediate conversational context and the shared knowledge that collaborators build together concerning their joint problems, plans, and interests.

Interactions are multimodal: people often sketch when they interact, to communicate both spatial ideas (e.g., maps, layouts) and plans and ideas (e.g., concept maps). Software collaborators should be able to participate in sketching, both understanding what is drawn and conveying spatial aspects of information by drawing as required. Understanding gestures and facial expressions is also important as a means of responding to the subtle signals that people tacitly use during conversation to keep things on track.

Collaborators also adapt over time to each other's communication styles and learn new tasks via interaction using natural modalities. This requires significantly more fluency in language than just question answering: A software collaborator needs to understand instructions and commands. It needs to be able to seek help when it is stuck, explaining what the problem is and taking advice about how to solve it.

What we need is systems that complement us … leading to a revolutionary impact of computing on all spheres of human life.

Efficient reasoning at scale: Filtering and combining information to produce useful knowledge requires combinations of deductive, statistical, abductive, and analogical reasoning. Deductive reasoning involves using logic to determine what does, or does not, follow from what is known about a situation. The person in a story who is pregnant cannot be a male, for example. Statistical reasoning helps determine which logically possible alternatives are more likely: given an ambiguous reference to someone who is pregnant, it is more likely the 20-year-old woman than the 80-year-old woman. Abductive reasoning concerns finding plausible explanations for a situation. For example, a scientist who suddenly stops publishing for a while might have changed institutions, gone into administration temporarily, or spent time doing classified research. Analogical reasoning involves using prior examples to reason about new situations and to construct generalizations based on similar situations. Historical cases are commonly used in political analysis, for example, and one mark of experts is their distillation of practical knowledge from experience. Assimilating knowledge into conceptual models requires reasoning to figure out how the new material fits into what is already known. This can, of course, require scrutinizing already accepted knowledge and rejecting it, if the weight of new evidence indicates that it is incorrect. Answering questions beyond simple fact retrieval also requires more reasoning. Subtle conclusions rest on either deeply reasoning or combining large numbers of disparate facts to reveal hidden patterns, or both. A software collaborator should support both interactive-time question answering and offline reasoning to handle more complex analyses.

Self-guided learning: Watson required the services of a large team of technically trained experts to hand-tune its algorithms and reading matter. Software collaborators should require no more routine maintenance than does a human collaborator, i.e., reading and conversation to keep in sync. They need to automatically identify their own conceptual gaps and formulate learning plans to increase their understanding. Unlike Watson, which was constructed to answer trivia questions on general knowledge, software collaborators should be capable of adapting to new tasks and subject areas automatically as their workloads change. They should automatically prioritize investigation of new source material and solicit specific input from their human collaborators when needed.

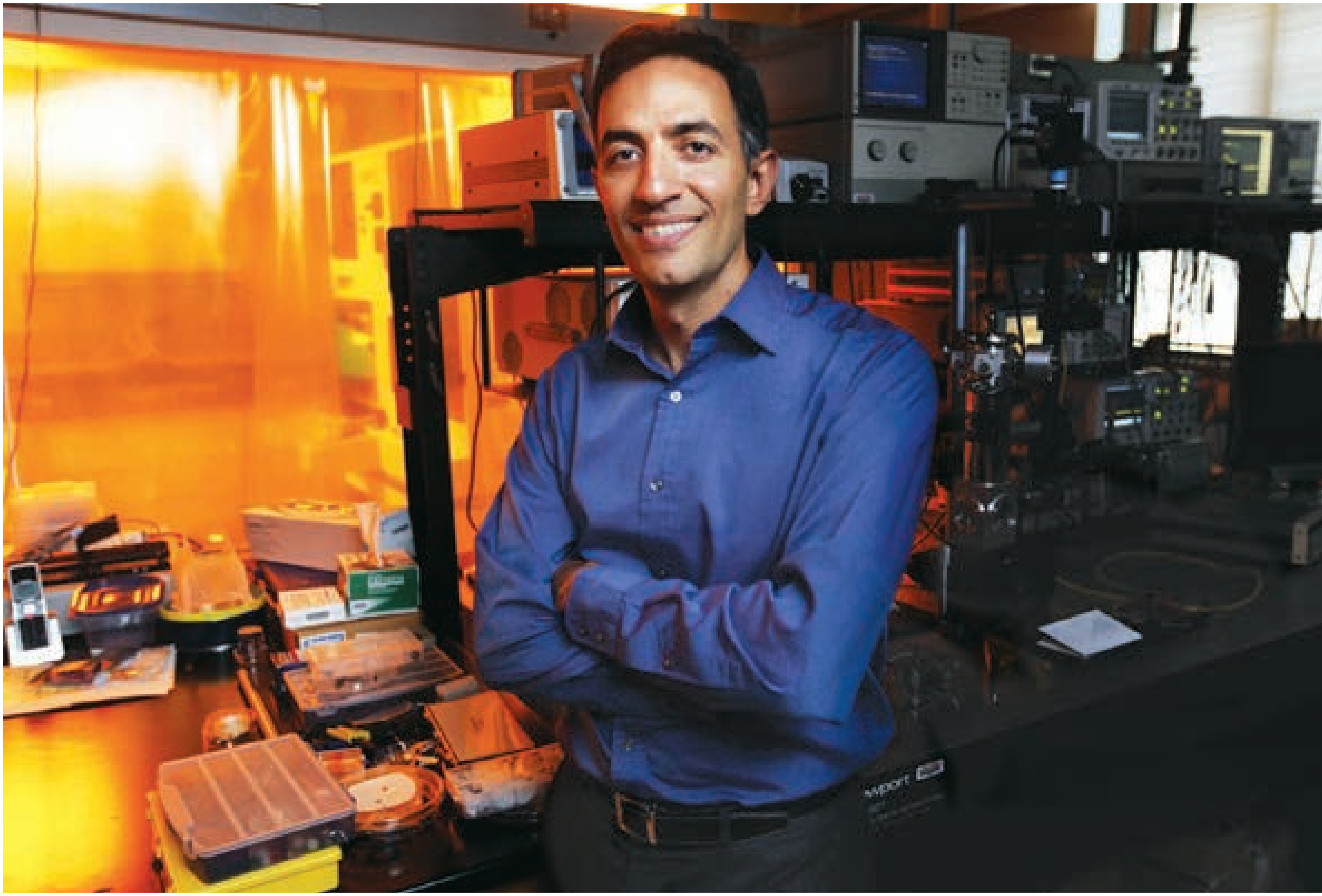
These four areas include many hard scientific problems; progress on them will move Watson-like systems from grand experiments toward software collaborators that will be useful in all walks of life. Scientists and engineers will be able to more easily focus their attention on aspects of the research literature that are relevant to their current problem. Analysts and journalists will be better able to "connect the dots" and spot patterns and problems that currently escape detection. Decision makers will have relevant precedents ready to hand, as well as help in generating scenarios describing possible outcomes. Teachers will have help in assessing student performance and finding new materials that could improve their classes.

The rising tide of big data can either become a deluge that leaves us gasping for air or the wellspring of information that our software collaborators sift, sort, filter, and organize to provide the information we need, when we need it. We think that creating Watson-like systems—and beyond—for everyone will be an even bigger benefit to humanity than Internet search. M

Ken Forbus
Walter P. Murphy Professor of Electrical Engineering and Computer Science

Larry Birnbaum
Associate Professor of Electrical Engineering and Computer Science

Doug Downey
Assistant Professor of Electrical Engineering and Computer Science



MODELED ON THE HUMAN EYE

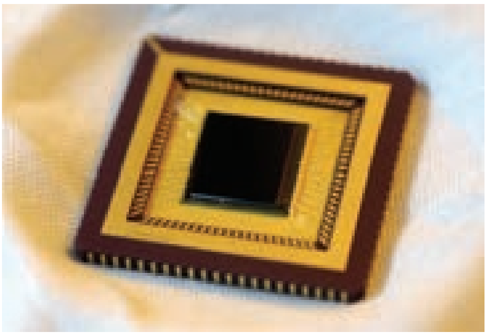
Taking inspiration from nature, Hooman Mohseni seeks the perfect single-photon detector

From the outside, Hooman Mohseni's camera doesn't look like much. Measuring nearly a foot long, its boxy tan body is more reminiscent of a '70s slide projector or dental x-ray machine than one of the world's best light-sensing devices.

But inside that unassuming exterior is an imager that rivals the human eye in its ability to sense the tiniest traces of light, but in a wavelength completely invisible to human eye. The result of six years of work, the one-inch flat square is made of tens of thousands of photon detectors, a type of light sensor not unlike those in cameras and cellphones.

Single-photon detectors are so powerful they can detect and respond to just one photon, the basic unit of light, and capture images in virtually pitch-black conditions. They hold promise for much more than imaging, though; once perfected, they might find application in everything from medicine to homeland security to quantum computing. So far, researchers have been unable to design a single-photon detector accurate and sensitive enough for most applications, but people are taking notice of Mohseni's camera. Taking cues from the human eye, Mohseni (PhD '01), associate professor of electrical engineering and computer science, has developed a single-photon detector that could lead to significant advances.

Single-photon detectors, previously a niche topic within the photonics field, became increasingly prevalent within the scientific community during the three years Mohseni worked in the photonics group at Sarnoff Corporation after receiving his PhD from Northwestern. Mohseni grew intrigued by the significant gap between the performance of man-made single-photon detectors and those found in nature. When he returned to



"The human eye is amazing in terms of sensitivity—many thousands of times better than the standard detectors we are using today. I wanted to know how this, nature's marvel, manages to reach that level of detection.**"**

HOOMAN MOHSENI

McCormick as an assistant professor in 2004, he immediately developed novel ideas to replicate nature's approach for photon detection in a new semiconductor device.

Within a year of his arrival as a faculty member he had been awarded close to $4 million in grants from the Defense Advanced Research Projects Agency (DARPA) and National Science Foundation to develop his single-photon detector. With the funding and researchers from his aptly named Bio-Inspired Sensors and Optoelectronics Laboratory, he set out to develop a light detector that mimics the eye.

"The human eye is amazing in terms of sensitivity—many thousands of times better than the standard detectors we are using today," Mohseni says. "I wanted to know how this, nature's marvel, manages to reach that level of detection."

To sense light, the eye uses rhodopsin, a collection of light-detecting molecules that float inside the retina's rod cells, forming a sort of web that is highly efficient at capturing photons. When rhodopsin interacts with light, a cascade of chemical reactions begins, at the end of which a single molecule is triggered to open molecular valves in the rod cell wall, beginning the process of transmitting signals to the brain. That combination—the net of rhodopsin funneling energy into a single molecule—makes the eye both extremely reliable and incredibly sensitive; after 30 minutes of darkness, every rod cell in the human eye is sensitive enough to detect a single photon.

Mohseni's design uses similar principles: a very large absorbing area that focuses all its energy into a nanoscale switch that controls the flow of electrons through the device. Not only is the resulting device far more sensitive than other single-photon detectors—currently 100 times more sensitive than other cameras at its wavelength—it also produces less "noise," blips of errant signals that skew results.

"Just like the rod cells in the eye, we have a single-photon detector that has a very high probability of detection and a very low rate of false alarms," Mohseni says. "And we are still far from the predicted performance limit of our device."

Although he knew he'd created something significant, Mohseni has been surprised by the amount of interest in his device, often from unexpected sources such as the medical community.

Because the wavelength at which Mohseni's camera operates—short-wave infrared—is the wavelength at which human tissue is most transparent, medical applications are likely. Mohseni envisions that his camera could eventually replace CT scans for some applications, achieving better images in a few seconds and eliminating radiation risks. Ultrasensitive and fast infrared imagers are also useful in astronomy because they can significantly increase the probability of finding Earth-like planets. And with another grant from DARPA, Mohseni's team just started working to perfect his single-photon detector for quantum computing.

"Our research could have a significant impact in a wide range of fields—enabling discoveries in astronomy and quantum physics, even new medical applications that could save lives," Mohseni says. "It's very exciting for my team." **M** Sarah Ostman

Prognosis: Better, smarter, faster

McCormick researchers help engineer a brighter future for patients at the Rehabilitation Institute of Chicago

In a lab on the 14th floor of a downtown Chicago research center, Patrice Loudin sits in front of a computer. As researchers look on, a large red dot appears on the screen; with the aid of a robotic sling, Loudin slowly raises her right hand toward the target. While an eye-tracking device on her head shows that she's aiming for the center of the circle, she manages only to graze its edge before slowly drawing her fingers back toward her lap.

Her aim may not be perfect, but the fact that Loudin is moving her arm at all is momentous: she is a quadriplegic. Using electrodes and a complex series of algorithms, this device-in-progress has provided the missing link between Loudin's intentions and her movements—allowing her to control her arm for the first time in two years. "It feels natural," Loudin says. "It feels like I'm using my arm naturally for the first time in a long time."

Moments like these are the stuff of dreams for patients, doctors, and researchers at the Rehabilitation Institute of Chicago—and for the McCormick researchers at their sides. Named the top rehabilitation hospital in America by *U.S. News & World Report* for 21 years running, RIC is a leading provider of physical medicine and rehabilitation services, both at its 182-bed inpatient hospital in Chicago and at more than 50 satellite locations in the metro area. It's also a hotbed for research, with its Searle Rehabilitation Research Center holding the title of the largest physical rehabilitation research center in the world.

A unique partnership between Northwestern and RIC has allowed several faculty members to hold joint appointments at McCormick and the Feinberg School of Medicine's Department of Physical Medicine and Rehabilitation, housed at RIC. The collaborations bring together medical experts and therapists with researchers from biomedical engineering, mechanical engineering, and electrical engineering who work toward a shared goal: improving the lives of patients.

"It's really nice to have these collaborations," says Eric Perreault, associate professor of biomedical engineering and of physical medicine and rehabilitation. "I have engineering colleagues in Evanston whom I work with quite closely, and I'm able to work with patients and clinicians in a hospital setting here. It's a nice synergistic relationship."

An occupational therapist fits Patrice Loudin, a quadriplegic, with an eye-tracking device in the lab of Eric Perreault (shown below). Researchers in the lab are developing an algorithm that can "decode" impulses from the brain and translate them into movement.

New hope for paralyzed patients

One day the device Patrice Loudin is testing could help spinal cord injury patients regain control of their paralyzed limbs. In many ways the 19-year-old is the perfect candidate for the research: since suffering a high-spinal-cord injury two years ago, she has lacked motor control over her body from the neck down. She does have limited control of her neck and shoulder muscles, however, providing an opportunity for Perreault and his fellow researchers to help determine how Loudin intends for her arm to move.

"After a spinal cord injury, the electrical signals that control movement are blocked at the site of the injury and cannot get to the relevant muscles. But many of those signals can still be recorded," Perreault explains. "By recovering signals related to the intended movement, such as in synergistic muscles above the injury, we can infer how the subject would like to move and then use our robot or another means to realize that intention."

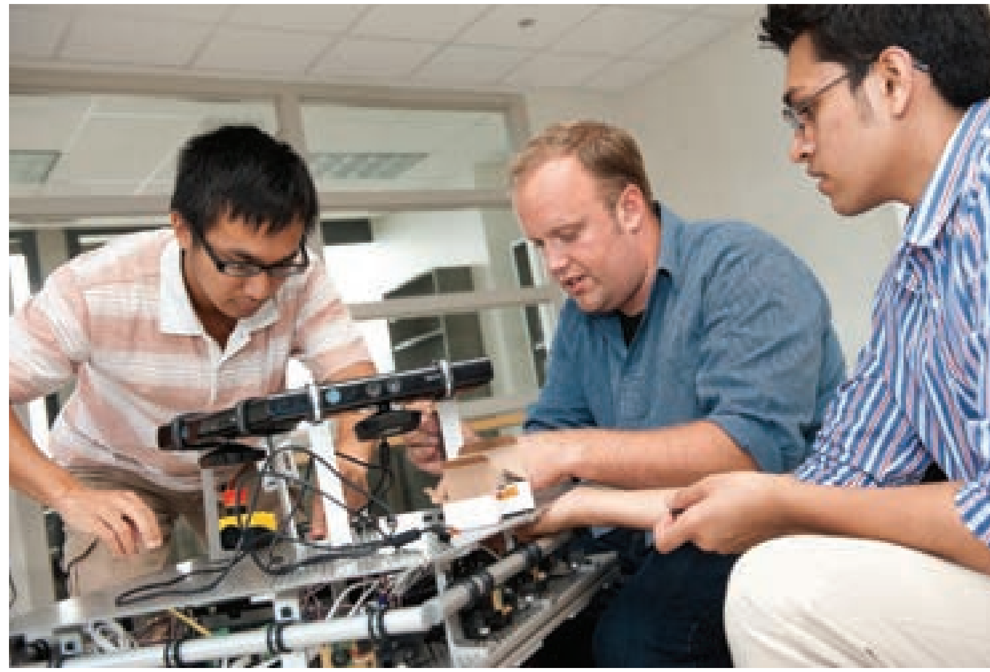
In essence, the goal is a device that can read a person's mind. For the past two years Perreault and PhD candidate Elaine Corbett have pursued this goal, working with researchers from RIC's Sensory Motor Performance Program, the Feinberg School of Medicine, and colleagues from Case Western Reserve University in Cleveland on a project funded by the National Science Foundation Program in Cyber-Physical Systems. They began by collecting data from 21 unimpaired subjects, developing a "user interface" that can translate thousands of intentions. Last summer they began using their algorithm with impaired patients.

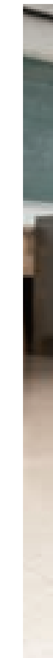
During Loudin's first laboratory session, researchers placed Band-Aid-like electrodes on her neck to monitor muscle activity and a reflective device over her eyes to follow her gaze. When a spot appeared on the screen, Loudin's occupational therapist instructed her to try to reach for it, as she would have before her injury. As she did, the algorithm translated the activity in her neck and eyes, deciphering where she wanted to move her arm. The computer then sent direction to a robotic arm, which was attached to Loudin's own arm, and it guided her hand to the desired location. In a perfect case, Loudin would have hit the circle in the center; that she just touched the edge of the circle could be due to weak signal reception in the electrodes, Perreault explained.

The ultimate goal of Perreault's research is to combine the movement decoder with a fully implanted system capable of stimulating the paralyzed muscles so the intended movement is restored without the need for a robot. This technology, known as functional electrical stimulation, has seen some success at Case Western Reserve, which pioneered much work in this area. For example, the Freehand system developed there has allowed many patients with less severe impairments to regain control of their hands. "This has allowed many people to feed themselves and write, when they couldn't before," Perreault says. "It's a dramatic improvement in quality of life."

The beauty of Perreault's algorithm is its flexibility: it can be applied to a variety of subjects with different levels of injury. "Every injury is unique," Perreault says. "This leads to each person with spinal cord injury having very different abilities. This algorithm can take those differences into account."

The technology is still in the early stages, though, and it's hard not to notice a tinge of disappointment in Loudin's voice when she asks how long it will be before the completed system, including the implanted stimulator, is available for more than this hour-long laboratory test. A viable implanted solution, she's told, is years away.





"Helping people stay mobile is one of the best things you can do for their independence and health and happiness. And as engineers, we are really well suited to study movement. It's physics, after all."

WENDY MURRAY

Smarter assistive devices

It may be missing its seat, but even in its current incomplete state, the automatic wheelchair whirring across Brenna Argall's 1,000-square-foot lab might be the smartest wheelchair you've ever seen. Using a suite of infrared and ultrasonic sensors and two Microsoft Kinects—the same sensors used in the Xbox—this wheelchair can sense its surroundings, avoiding collision with objects in its path.

On its first run the wheelchair zips around the lab, navigating tight turns and avoiding walls and chairs like an oversized Roomba vacuum cleaner. Soon, Argall hopes, the chair will be able to do more, such as recommending alternate routes to avoid unsafe conditions—regardless of whether its rider has even noticed a problem. Moreover, the wheelchair will work with its owner to learn new behaviors, fine-tuning itself for his or her needs and wants.

"My interest is in making robots that can both learn and make decisions," says Argall, June and Donald Brewer Junior Professor of Electrical Engineering and Computer Science and assistant professor of physical medicine and rehabilitation. "We're talking about devices that can share control with the patient."

Argall is Northwestern's first joint appointment to RIC from the Department of Electrical Engineering and Computer Science; new to rehabilitation, she comes to McCormick from a background in robotics and machine learning. Her field is largely new terrain in rehabilitation; while robots are sometimes used in today's rehab work, they serve primarily as tools for physical therapists. (For instance, KineAssist, a device created by two McCormick mechanical engineering professors, senses when a patient loses his balance and holds him upright.)

Argall envisions a marriage of rehabilitation and artificial intelligence that could make therapy more natural and user-friendly. She points to clinical research that indicates there is a one-year window following an injury when patients are willing to explore new coping mechanisms and control paradigms.

To maximize benefit in that short time, devices must be as intuitive as possible; too often, Argall says, even sophisticated assistive devices like complex electric prostheses are used simply for aesthetic purposes because the user is uninterested or unable to learn the control. "In our lab, instead of the human needing to learn how to use the machine, the machine learns from and is trained by the patient," Argall says. "After the year window, patients have figured out what works for them and are not as willing to learn something new, especially when relearning involves a machine that may not be intuitive."

Using artificial intelligence with human subjects can be challenging because of a lack of guarantees on control. When using robots in the traditional low-level control scenarios of mechanical engineering, researchers can say with certainty how the device will behave under certain circumstances. When developing robots that can sense and respond to their environment using machine learning, certainty decreases, resulting in potential problems with human subjects and a slowing of the invention process. "This technology has huge potential because you can expand and generalize it in so many ways," Argall says, "but we also have to work with these unknowns."

Argall recently started working on the uncertainty problem with robotics expert Todd Murphey, associate professor of mechanical engineering. In the end, Argall and Murphey envision robot systems that can be taught by a human and still keep all of the formal control guarantees like stability. "We're starting to build bridges between the machine-learning, data-driven background I offer and the formal control theory he offers," she says, "seeing if we can find some middle ground."

Brenna Argall (far left) and her team (center) work to create robots that can learn and make decisions—such as a robotic wheelchair (right) that can learn from its owner and avoid collisions. It has taken years for Wendy Murray (below) to develop her incredibly complex model of the human arm and hand; now its simulations shed light on the limb's complicated mechanics.

Deconstructing the arm

While much of the progress at RIC can be seen with the naked eye, other work is more subtle. For some projects, years' worth of data collection and careful study may be required before there is any contact with patients.

That's the case with research by Wendy Murray (PhD '97), associate professor of biomedical engineering and physical medicine and rehabilitation, on conditions of the hand and arm. Since her days as a PhD candidate in McCormick's Department of Biomedical Engineering, Murray has been using the principles of mechanical engineering to study the arm's complicated mechanics: what each muscle does, how it attaches to the skeleton, how it interacts with the rest of the system. Years of unglamorous work gathering data from the Feinberg School of Medicine cadaver lab eventually yielded powerful results: a computational model of the human arm that incorporates data about every component into an adaptable model.

One of the conditions Murray studies is osteoarthritis, a degenerative joint disease that can make writing a note or turning the page of a book a painful task. Treatment sometimes involves surgery, but the procedure carries significant risks, and outcomes vary greatly from patient to patient. Murray, along with Jen Nichols, a PhD candidate in biomedical engineering, and Michael Bednar, a hand surgeon at Loyola University, is working to find out why. Are the variations caused by subtle differences in how surgery is performed? Or slight differences in the physiology of patients? If the latter, what muscle, bone, or ligament is the key?

The answers are elusive, in large part because the human arm and hand are so intricate. "If you look at illustrations of anatomy, you can see the upper limb is incredibly complex," says Murray. "The way the joints move is complicated, the way the muscles attach is complicated. It's this elegant, incredibly designed system, and from a purely quantitative sense we don't know that much about how it works."

Murray's model—which was first created during her graduate work with advisers Scott Delp and Tom Buchanan (now at Stanford University and the University of Delaware, respectively) and further developed through Delp and Murray's collaboration with Kate Saul during Murray's tenure at the VA Palo Alto—provides a tool for understanding the workings of the arm in ways not possible with research on human patients. "We can simulate things in a model and then take it apart and say, 'This is the muscle that is causing this,'" Murray says. "We have taken all this sophisticated information and put it in one place."

Research that once relied on slowly collected data from numerous patients is now as easy as changing a few numbers in a simulation. With some minor tweaks, for instance, researchers can simulate a surgery on a patient weakened by osteoarthritis, eventually developing new surgical techniques targeted toward people with certain impairments. "You can do thousands of simulations, and patterns start to emerge," Murray says. "Then we are able to take these results to clinicians like surgeons and physical therapists, and they start to say, 'You know, we've seen something like that in the clinic.'"

Collaborating with McCormick colleagues has allowed Murray to branch into a new field of inquiry: how muscles interact with the brain. Working with Eric Perreault and other researchers, Murray studies the results of tendon-transfer surgeries. In these procedures, muscles are disconnected and reattached to give patients the ability to move a paralyzed limb; for example, a muscle from the elbow may be used to power the

"For the first 15 years after my stroke, I avoided zipper jackets entirely. It's a problem for so many people, and there's not much on the market that can help."

JOY RAY, STROKE PATIENT

thumb. The success of tendon transfers relies not only on surgical procedures but also on the follow-up; patients must learn how to control their muscles in a new way. The results are mixed. While patients generally learn to use the limbs, they frequently lose range of movement. Interestingly, evidence indicates that this loss is due to failing communication from the nervous system instead of trauma to the muscle or bone.

"How does the brain suddenly adapt to the fact that when it wants to bend the elbow, it is moving the thumb? And how can we help people who have had this surgery use these limbs optimally?" Murray says. "Combining Eric [Perreault]'s and my complementary approaches to study the biomechanics and control of the upper limb, we can begin to bring these pieces together to help these patients access their own strength."

Currently Murray is working with mechanical engineering's Todd Murphey on a new project funded by the National Institutes of Health, investigating whether biomechanical modeling could help develop a controller for complex hand movements for prosthetics. "The thought is that if we embedded this model into a prosthetic hand, could the wearer make the prosthetic move just by thinking about how they used to move their hand?" she says. "The device could pick up signals, and the model could predict the movement that would have happened."

The ambitious project brings together experts from Northwestern, the University of Colorado, and the Defense Advanced Research Projects Agency. As a first step, researchers collected electromyography data of different hand and arm movements and entered the data into their algorithm. The simulation was so complex it took three days to run.

If the hopes for such biomedical research can be realized, the impacts on the disabled and aging population would be profound. "There's no simple solution, but this is a real issue our society has to deal with," Murray says. "Helping people stay mobile is one of the best things you can do for their independence and health and happiness. And as engineers, we are really well suited to study movement. It's physics, after all."

Undergraduates design products for RIC patients

Since 2003, McCormick undergraduates have also been engaged in a collaboration with RIC through a required two-quarter course, Design Thinking and Communication (formerly Engineering Design and Communication), in which freshmen design solutions for patients. The arrangement offers an excellent learning experience for students—many of whom are taking their first stab at design—while the students' fresh perspective and outside-the-box thinking offer real solutions to RIC patients.

One of those patients is Joy Ray, who lost control of her right arm after suffering a stroke at the age of 33. Once-simple tasks like tying shoes and washing dishes were suddenly a source of frustration; zippers were especially problematic. "For the first 15 years after my stroke, I avoided zipper jackets entirely," says Ray, now 59. "It's a problem for so many people, and there's not much on the market that can help," she says.

Last spring a team of four undergraduates from the Design Thinking and Communication class met with Ray to discuss the problem. Her struggle to use a zipper with only one hand was clear, but the solution was anything but. At first the students planned a device that would clip to Ray's pants, firmly holding one side of the zipper so Ray could focus on plugging the loose end. It didn't work. "The sides of the jacket kept drifting apart," says Vinithra Rajagopalan (biomedical engineering '15). "We realized we needed a component that would hold them together."

By the end of the quarter the design had changed considerably, into a metal U-shaped device with two clips to hold the jacket closed and keep the zipper taut. The device still ran into snags in a final unveiling with Ray: the fabric flap over the zipper kept getting in the way, and the design couldn't easily be flipped to accommodate men's jackets, which zip on the opposite side.

"It's kind of nerve-wracking. The act of engaging a zipper has a lot more to it than we originally thought," admits Cheyenne Lynsky (chemical engineering '15). "The stress comes from not wanting to disappoint. We've tried really hard to make something that will make her life easier."

Problems are not always solved in one quarter. Many DTC projects span several quarters, with different teams contributing to a design before a client considers a problem solved. One long-term project was especially ambitious: a wheelchair training device for wheelchair athletes that could simulate an increase in elevation. McCormick students started last year by interviewing athletes and RIC staff to learn about the shortcomings of the institute's current equipment. They heard that athletes were not able to get onto the existing trainer by themselves; two staff members had to lift them. Furthermore, the trainer provided only one level of resistance and accommodated only one shape of athletic wheelchair, so many athletes couldn't use it.

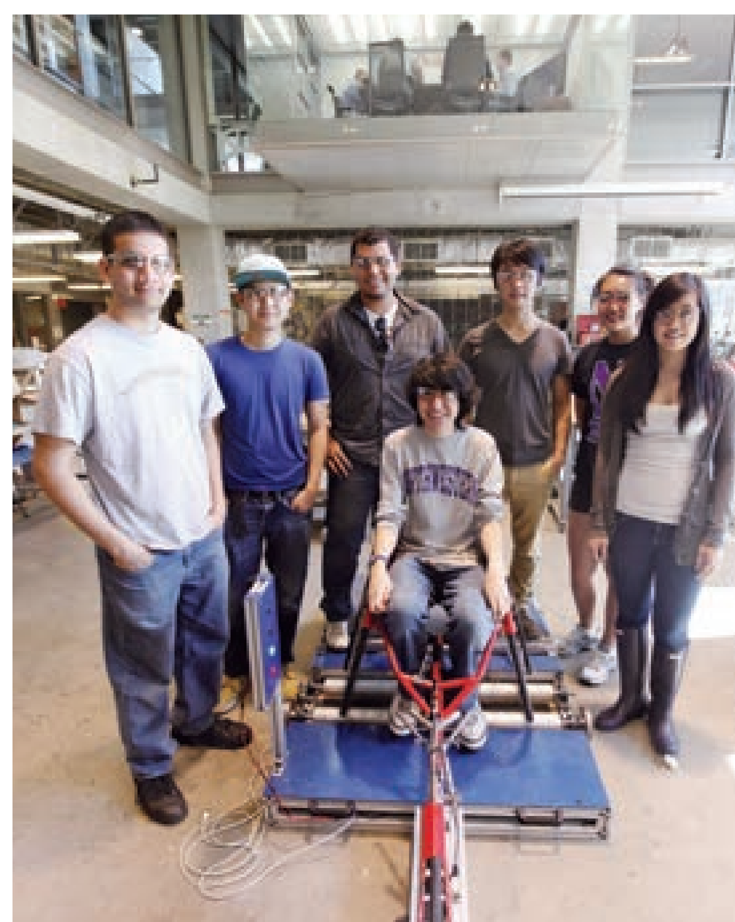
"We asked the class to tackle all these shortcomings and create a piece of exercise equipment that could be utilized much like a treadmill but by wheelchair users," says RIC program specialist Eric Johnson.

A first prototype created by students addressed all these concerns; it also featured a locking system to secure wheelchairs and a computerized control system to vary the strenuousness of workouts and to provide performance readouts. Later groups refined the design with a lower profile, allowing more independent accessibility, and a more secure lock to secure the wheelchair to the device.

In the end, three classes worked on the wheelchair trainer. Johnson says he hopes it will be added to the RIC facility in the near future. "Each of the teams worked to encompass every aspect of my vision in this device," Johnson says. "It was a great experience for all of us."

M Sarah Ostman

(Opposite page) Design Thinking and Communication students (from left) Kashyap Saxena, Vinithra Rajagopalan, Hayley Blythe, and Cheyenne Lynsky created a device to help stroke patient Joy Ray (far left) zip a zipper with the use of only one hand. (Below) Other groups have worked for several quarters perfecting a wheelchair treadmill for athletes at the Rehabilitation Institute of Chicago.



Concrete results

Since 1969 Zdeněk P. Bažant has been a respected presence among McCormick's civil engineering faculty. As a world leader in scaling research in solid mechanics, he is perhaps best known for developing widely used models to assess the safety of large quasi-brittle structures, such as bridges, dams, ships, and tall buildings.

But Bažant, McCormick School Professor and Walter P. Murphy Professor of Civil and Environmental Engineering, almost saw his civil engineering career stymied before it could begin. He was born in Prague to a sociologist and a geotechnical engineering professor; four generations before him had been civil engineers. "I was lucky to have been born into a great intellectual family," Bažant says, "but my family background was politically unlucky for those times."

Communists took control of Czechoslovakia when Bažant was 10 years old. They banned his mother's profession of sociology as "bourgeois" science, and her boss, a family friend, was executed on trumped-up charges. The government seized the property of his maternal grandmother, a successful entrepreneur. As a "bourgeois child," Bažant was slated for an apprenticeship in the coal mines. He still calls this period the "biggest crisis" of his career.

Bažant's future might have been set then if it hadn't been for an illness that his family could exaggerate to disqualify him physically for the mines. Eventually he was able to enter high school, where he excelled in math and became a winner in the Mathematical Olympics of the country. In 1960 he graduated first in his class from the Czech Technical University and was asked to join the Communist party. He declined. This made him a declared opponent, and his application for graduate study was rejected; the Communists commonly denied higher education to political opponents.

Bažant was assigned to work in a state-run engineering firm that designed and built bridges and highways. "I liked it, and in retrospect it was a valuable experience," he recalls. One particular job impacted his career. While he was supervising work on an innovative arch, the reinforcement truss of the bridge began oscillating; Bažant immediately brought work to a halt. After some calculations, he realized that the spatial bracing in the structure was insufficient, and if work had continued, the entire structure would have collapsed. This episode piqued Bažant's lifelong interest in structural stability.

In the late 1950s a ski injury spurred Bažant to invent one of the earliest safety release bindings. "The way you attached your boots to your skis back then was to tie them tightly with belts," he says. "It caused terrible injuries." He patented the device, and by the early 1960s one-third of all skiers in Czechoslovakia were using his invention. (Today the binding is on display at the New England Ski Museum in Franconia, New Hampshire.)

But Bažant still wanted to get a PhD. He exploited the fact that under Communism it was possible to obtain a PhD "externally," provided one had a recommendation from the party cell of the firm. He managed to get it. "It meant I had to study alone while working full-time and then take course exams without ever setting foot in a classroom," he says. "I saw my adviser twice: once when I explained what I wanted to do and three years later when I brought my dissertation."

Bažant received his PhD in engineering mechanics from the Czechoslovak Academy of Sciences in 1963. Four years later he got married in a small village, where authorities would be slow to register the union. Thanks to a period of political relaxation that preceded his country's Prague Spring reforms, Bažant and his wife managed to leave the country. They left separately—married couples were not allowed to leave together—and reunited in America.

After research appointments in Toronto and Berkeley, Bažant joined Northwestern's faculty in 1969 and began studying concrete creep and hygrothermal effects in nuclear reactor structures. He invented the age-adjusted effective modulus method, which allows simple prediction of long-term concrete creep effects and is now featured in virtually all design standards. At McCormick Bažant also devised his size-effect law—a short formula that reflects the fact that quasi-brittle failure is decided not only by material strength but also by dissipated energy. The formula—his most widely known result—now forms the basis for a standardized fracture test. His related crack band model, a law to explain a type of concrete failure, is widely used in industry and special commercial software and became his most cited research.

In a current project Bažant is collecting data about bridges that have deflected excessively. "These deflections and the associated cracking cannot be attributed to poor construction," Bažant says; they are the consequence of procrastination in updating design codes. "I have been saying for years that the design codes are incorrect, and finally we got the evidence."

The result of this work will be a probabilistic prediction of creep effects in concrete structures for hundred-year lifetimes. The project has also intensified another of Bažant's passions: seeking transparency in his field. Collecting data about the 69 prestressed bridges has proven very difficult for the international committee he founded because of a common practice in civil engineering failures: the sealing of technical data after litigation. Bažant fights for the end of this practice. "In commercial aviation, data concealment is a crime"—and with good reason, he says. "Understanding failures means you can prevent them next time."

Among his other accomplishments, Bažant's work has helped in the development of lighter, more fuel-efficient cars with improved crashworthiness; his laws have also helped the navy design large sandwich panels for the hulls of long superlight ships. He developed better material models for the penetration of missiles into hardened concrete structures, and he used his size-effect law to calculate the load capacity of floating sea ice plates. He has published six books and is working on a seventh.

Bažant remains one of the most respected figures in his field, evidenced by his induction into the National Academy of Engineering (1996), National Academy of Sciences (2002), American Academy of Arts and Sciences (2008), and five European national academies, as well as by his impressive collection of medals and seven honorary doctorates. Of all his accomplishments, Bažant points to his best-known result as his proudest. "My size-effect law has been my highest achievement, because it is simple and useful," he says. "Simplicity and usefulness are the most satisfying attainments in science." M Sarah Ostman

LEAVING COMMUNIST CZECHOSLOVAKIA BEHIND, ZDENĚK BAŽANT HAS MADE HIS MARK IN AMERICAN CIVIL ENGINEERING

Printed in **3D**

Undergraduate's model of campus displayed in Tech lobby

With finals approaching last spring, junior Ben Rothman had more on his mind than exams. Around midnight each night, he trekked through the subbasement of the Ford Motor Company Engineering Design Center to a prototyping lab. He plugged a flash drive containing his self-designed digital map of the Evanston campus into a computer attached to a sleek, hatched-door, silver machine. He filled the machine with white powder from a nearby bucket and pressed Print.

While Rothman slept, the device went to work on a small plate, laying down layer upon layer of powder, ink, and adhesive. From the layers emerged tiny replicas of the Technological Institute surrounded by rows of bike racks; tennis courts, complete with bleachers and lights; and three miniature fountainheads poking out from Northwestern's lagoon. After two weeks of nightly outputs, a five-foot-wide scale model of the entire Evanston campus in three dimensions was complete.

While still in its infancy, 3D printing is part of a larger trend of "smart manufacturing" that promises to be one of the great technological transformations of our time.

"I tried to make the buildings as accurate as possible," says Rothman (EECS '14), "down to the placement of the windows and doors."

Gone are the days of foam core, razor blades, and modeling by hand. The cutting-edge manufacturing technique known as "additive manufacturing" (or more colloquially, 3D printing) can now transform digital files into three-dimensional objects. McCormick's 3D Systems Z450 is capable of churning out perfect scale models in a fraction of the time of traditional methods, depositing thousands of 0.1-millimeter-thick layers on top of one another until objects take shape.

While still in its infancy, 3D printing is part of a larger trend of "smart manufacturing" that promises to be one of the great technological transformations of our time. In a January 30 *Wall Street Journal* op-ed, Dean Julio M. Ottino and McCormick Advisory Council member Mark P. Mills argued that smart manufacturing will be as transformative to this century as electricity and automobiles were to the last. One day, they wrote, we will achieve "the Holy Grail: 'desktop' printing of entire final products from wheels to even washing machines."

Rothman doesn't shy away from new technology; he's been drawn to it all his life. "When I was little, I always wanted to know how things worked on the inside, taking apart my toys and often failing to put them back together," he recalls. "My dad, a lawyer, talks about how he directed my brother and me toward technology by always buying the latest gadgets and passing down his old 'toys' to us." Rothman would spend hours playing computer games like Math Blaster and Dr. Brain; by his freshman year at Northwestern, he says, he was "wasting" 20 hours a week playing video games. "I decided I would try to do something more productive with that time," he says.

Over winter break at his parents' Wilmette, Illinois, home, using the sandbox-style video game Minecraft—where blocks are arranged to build landscapes, towns, even entire recreations of *Star Trek*'s Starship Enterprise—Rothman started building a virtual copy of his on-campus residence, Slivka Residential College.

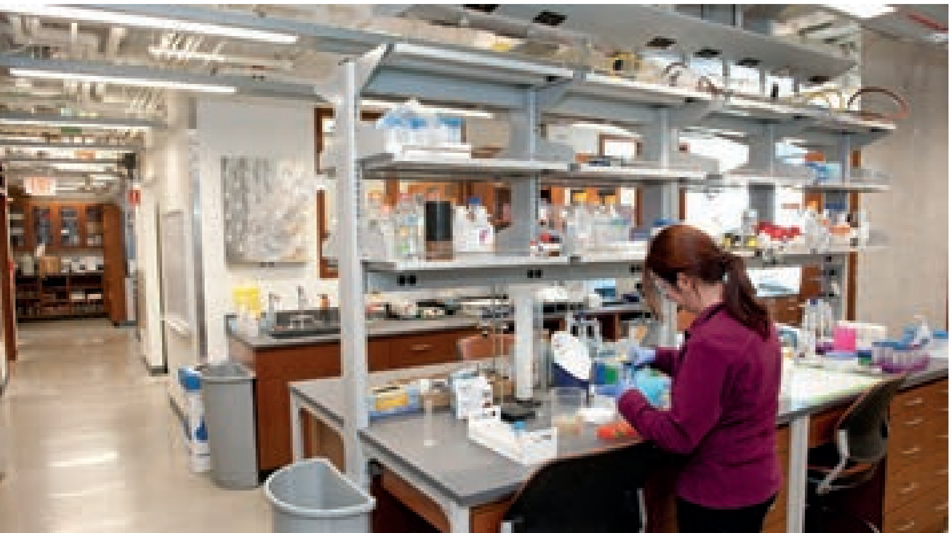
"I thought, Slivka looks a little lonely," recalls Rothman, "so I guess I'll build [neighboring residence hall Ayers] CCI. Then it was, CCI looks a little lonely; I guess I'll build McCulloch." Within a couple of months, Rothman, using mapping websites as a reference, had recreated on that computer program every building from the Rebecca Crown Center to the northern tip of Northwestern's Evanston campus. He had also built the interiors of Slivka, CCI, Tech, and the Ford Motor Company Engineering Design Center. (The interiors were lit by torches—the only light source available in Minecraft—leaving them slightly reminiscent of dungeons.)

Rothman released an eight-minute YouTube video showcasing the project, which caught the attention of reporters at the *Daily Northwestern* and *North by Northwestern*. When Dean Ottino learned about it, he wanted to share the project with the entire McCormick community. New software makes it possible to export Minecraft files to 3D printers, and an idea was born: Rothman would turn his computer files into a scale representation of the entire campus, to be displayed at Tech.

"Technology like 3D printing will significantly change the way we shop, work, and live," Ottino says. "At McCormick, we don't just want to embrace these changes, we want to be at the front line. This project is one way of doing that publicly, and it's a welcome addition to the Tech lobby."

Completed at the end of spring semester, the model was unveiled in July at its new home between the entrances to the Ryan Auditorium in the Tech lobby. For Rothman, who is considering a career in web development, watching his hard work transformed from his computer screen to three dimensions has been gratifying.

"The fact that you can print all of Northwestern in 3D," Rothman says, "is just really incredible." **M** Sarah Ostman



WILLENS WING WELCOME

This fall students returned to Tech to find workers putting the finishing touches on the new Willens Engineering Life Sciences Wing, a six-story, 50,000-square-foot addition for students and faculty in the life and biomedical sciences. Located on the northern side of the building, the LEED Silver-certified Willens Wing features an airy two-story atrium with common areas for group work and informal meetings. Demonstrating the need for the facility, students have quickly filled the common spaces. The facility, made possible by a generous gift from Ronald and JoAnne Willens, provides a permanent home for the Integrated Molecular Structure Education and Research Center and new offices and labs for eight McCormick faculty members from the biomedical and mechanical engineering departments. The wing will be formally dedicated December 9.

a tale of three companies

Students begin building their own businesses even before graduation

Ask students what keeps them busy outside the classroom and you're likely to get a wide variety of answers. From lab researchers to lacrosse champs, code writers to sorority sisters, Northwestern has them all—even claimants to a title for which many high achievers have to wait until middle age: CEO.

Above: The NuMat team (left to right): Omar Farha, Ben Hernandez, Chris Wilmer, and Tabrez Ebrahim.

A growing number of students and recent alumni are getting an early start at startups, using the skills they gained at McCormick and other Northwestern schools—as well as the assistance of the University's growing suite of entrepreneurship classes and resources—in money-making endeavors. The Farley Center for Entrepreneurship and Innovation, an incubator space in downtown Evanston, and five NUvention courses bring together students from across the University to start businesses.

Why the startup frenzy? Not all students are destined to be chief executives at 20, but they can all benefit from the skill set that entrepreneurship builds, such as problem solving, communication, and business savvy. And for those who do catch the startup bug, well, Facebook founder Mark Zuckerberg has already demonstrated how far college-student entrepreneurs can go.

NuMat Technologies took first place—and $100,000—at the US Department of Energy's inaugural National Clean Energy Business Plan Competition, part of the Obama administration's Startup America Initiative.

PAVING THE WAY FOR CLEAN-ENERGY VEHICLES

A PhD candidate in chemical and biological engineering, Chris Wilmer never imagined he'd be standing in a photo op at the White House holding an oversized check. But there he was on June 13, as his NuMat Technologies was announced as the winner of the first-ever US Department of Energy's National Clean Energy Business Plan Competition. NuMat had bested five other regional prize-winning teams—Stanford's, Columbia's, and MIT's among them—in this segment of the Obama administration's Startup America Initiative. The prize was $100,000 in cash and $80,000 worth of in-kind services, including technical, design, and legal assistance.

The national competition was the fifth business-plan contest NuMat had won in as many months. From the grand prize at the Rice Business Plan Competition to a GOOSE Society Investment Prize, Wilmer and his three partners had already netted more than $1 million in cash and in-kind services; attracted national media attention from *Fortune*, *Crain's Chicago Business,* and *BusinessWeek;* and been invited to ring the closing bell at the NASDAQ not once but twice.

The fast rise can be traced in part to Wilmer's competitive fever; he entered and won more than 19 competitions during his McCormick career. It was an Innovative Minds grant, awarded by the law firm Perkins Coie in February 2011, that connected Wilmer with a potential collaborator interested in pitching a business around research Wilmer had done as a PhD candidate in the lab of Randy Q. Snurr, professor of chemical and biological engineering. The research was on porous crystals called metal-organic frameworks that are capable of storing natural gas and could make it possible to easily use the clean energy in cars. Perkins Coie intern Tabrez Ebrahim, a student in the JD-MBA joint program of the Kellogg School of Management and the School of Law, reached out to Wilmer about collaborating. They decided to enter the Clean Energy Challenge, an annual business competition that awards cash prizes to top Midwest clean-tech entrepreneurs. The grand prize winner would also earn the chance to compete in the US Department of Energy challenge.

The pair decided on a name—"NuMat," short for "Northwestern University Materials" and a spin on the stock company name NuCo—but otherwise "we had no idea what our business model was," says Wilmer. "We went into the competition saying, 'There are these materials called MOFs, they have all these different applications, and we plan to make a business around them somehow.' That was good enough to get us through the first round, and from there it just kept building."

Wilmer and Ebrahim knew they would need more hands on deck, so they invited Ben Hernandez, also pursuing a JD-MBA at Northwestern, and Omar Farha, a research associate professor of chemistry in Weinberg College, to join the company. Hernandez brought years of business experience to the team; Farha's "supercritical activation" technology, developed in the lab of Joseph T. Hupp, professor of chemistry in Weinberg, gave NuMat a unique competitive advantage.

Unlike many successful startups, NuMat hasn't brought on a seasoned leader; Wilmer (chief technology officer) and Farha (chief scientific officer) spearhead research, while Ebrahim (chief operating officer) and Hernandez (chief executive officer) steer the business end. Wilmer says the partners have grown into their roles. "As we've accrued contest winnings, engaged legal counsel, and executed other important business activities, we've matured a lot," he says. "We're all much more knowledgeable about business and the process by which technology is commercialized."

In July NuMat logged another achievement: along with Northwestern, the company was part of a team that won $1.5 million in funding for natural gas vehicle technologies from the US Department of Energy Advanced Research Projects Agency–Energy.

The company is a source of pride on campus. "NuMat has set a new benchmark for success among student and faculty startups at the University," said Farley Center director Michael Marasco. "It's exciting to see enthusiasm in fields like clean tech that haven't recently held the same cache as web app companies. It adds rich diversity to our growing student and alumni portfolio and should encourage future teams to take that first step out of the lab or classroom."

With one year remaining at McCormick, Wilmer is preparing to defend his dissertation and applying for faculty positions. "I want to help NuMat develop into a large company and see it solve important world problems," he says, "but my ultimate goal is a professorship. Ultimately I'd like to spin out more companies as a university professor."

SwipeSense founders Mert Iseri (left) and Yuri Malina went through their share of iterations before landing on a winner.

THE 38TH TIME IS THE CHARM

Young entrepreneurs make their share of mistakes—and Mert Iseri (combined studies '11) and Yuri Malina (integrated science '12) were no exception. The pair, cofounders of the student group Design for America, have spent three years working on SwipeSense, a hand-sanitizer dispenser that hospital employees can wear on their belts. The goal is to reduce hospital-acquired infections, which kill 90,000 people per year in the United States.

It's a noble idea, but the execution took some work. Early prototypes were clunky and didn't work quite right. "One time I met with a potential investor, and he asked if I had a SwipeSense with me," recalls Iseri. "I said, 'Yes, I do!' I handed it over and next thing I knew, it's leaking all over his pants. He was wiping at it, saying, 'Is this going to stain?'"

Now, after 38 iterations of SwipeSense, Iseri and Malina have something to be proud of: a sleek, white plastic design with a growing reputation in the medical device community.

SwipeSense got its start at the beach during the 2009 Summer Studio of Design for America, now a nationwide network of interdisciplinary student teams using design to create local and social impact. Partnering with NorthShore University HealthSystem's Evanston Hospital, a Northwestern Design for America group had observed doctors, nurses, and hospital staff to gain insights about hand-hygiene practices. But the crucial idea came when group members Malina and Iseri took a nighttime break at the Evanston waterfront, and Iseri wiped his sandy hands on his pants. "If you're a five-year-old on a playground and your hands get dirty, what's your impulse? You wipe them on your pants," Malina says. "What if hand washing in a hospital setting were that easy?"

Following up on their idea after the Summer Studio ended, Iseri and Malina set off to create the perfect prototype of a device that dispenses hand sanitizer when you swipe your hand across it. They started small, following the "lean methodology" of startup companies developed by Silicon Valley entrepreneur Eric Ries. The business approach relies on scientific experimentation and interaction with customers to meet the demands of the customer base without large upfront funding.

It took 40 hours to make each prototype using computer modeling with Arduino, an open-source electronics prototyping platform; 3D printing; and sanding and gluing. That may seem like a lot of time, but "it would have taken a year to do it 10 years ago," Malina says. "We never had more than five SwipeSenses at any time," Iseri adds. "There's no need to invest in developing something until you have feedback from your customers."

Meetings with clinicians and hospitals suggested changes, such as a tracking system that uses a wireless Internet connection to track each time the wearer sanitizes his hands; hospital officials could use the data in reports to health officials or in case of lawsuits. Malina and Iseri also nixed the swipe-dispensing motion for a simpler, more reliable push mechanism.

In January SwipeSense was one of 10 health-related startups to receive funding from Healthbox, a division of the Chicago-based new business incubator Sandbox Industries. Malina and Iseri were awarded $50,000 in seed money, as well as business advising, legal assistance, and three months of office space in downtown Chicago. They had the chance to pitch their business to investors at an "investor day."

Now working in Northwestern's incubator space in downtown Evanston, Iseri and Malina are raising their first round of funding—$1 million—from a handful of angel investors and venture funds to help bring SwipeSense to hospitals across the country. They are in the midst of their first trial with Northwestern Memorial Hospital: they will spend four weeks monitoring hand-washing practices of nearly 100 nurses to get a baseline before introducing their device for comparison. They plan to conduct pilots at a total of six Chicago-area hospitals to prove the impact of their technology and land their first customers.

"When we actually have the data that says SwipeSense reduces infection, that's when this is going to really take off," Malina says. Team SwipeSense has already been contacted by hospitals in the United States, the United Kingdom, the Middle East, and North Africa. "Infection really is a global issue," Iseri says, "and the way to fix it is hand sanitizing."

Hannah Chung and Aaron Horowitz with Jerry the Bear, a stuffed mechatronic bear that teaches kids how to manage type 1 diabetes.

FOR KIDS WITH DIABETES, A BEAR-Y HELPFUL TOOL

Understanding how your body reacts to certain foods can be difficult for an adult, let alone for a four-year-old. Jerry the Bear can help. Created by Hannah Chung (mechanical engineering '12), Iseri, and Malina as Design for America's first-ever undertaking, and now owned by Chung and Aaron Horowitz (combined studies, mechatronics and user interaction design '12), the stuffed mechatronic bear helps teach children how to manage type 1 diabetes. A screen on the bear's belly shows when his glucose level is low; Jerry perks up when he is fed certain foods or given an insulin shot. He can even make comments such as "I feel great!" and "You're really good at this!"

In 2009 Jerry the Bear's creators won the "most creative" award in the Diabetes Mine Design Challenge, which asked teams to create new tools for improving life with diabetes. The project really got under way when Horowitz came on board a year later.

Both Chung and Horowitz had personal experiences motivating them: Chung's father and grandparents have type 2 diabetes, and her grandfather died from hypoglycemia. Diagnosed with a hormone deficiency as a child, Horowitz was subjected to regular shots for years, leaving him sympathetic to the plight of diabetic children and their families.

"When your child has diabetes, you might only get 30 minutes with the doctor, and the lessons you learn there have critical consequences," Horowitz says. "Behavior changes by building habits, and that's not something that happens in 30 minutes." Jerry the Bear reinforces the lessons over and over in a fun way.

Today's Jerry, with a huggable body and toolkit backpack, is the result of three years of trial and error. In the early iterations the bear would tell you and his eyes would droop when he was feeling poorly. The child, whose target age was three to seven, could feed him one type of food to boost his glucose by 10 points or give him a fake insulin injection to lower it. A finger-pricking mechanism was added, allowing the child to test Jerry's glucose levels. Jerry was trying to do too much. "The toy became too complex," says Chung. "We had to research and determine what was most important."

As they refined their product, Chung and Horowitz got a huge boost: the Betaspring business accelerator program, in Providence, Rhode Island, admitted their startup company, Sproutel, last February. Chung and Horowitz, who were halfway through their senior year at McCormick, made arrangements to get credit for the experience and graduate on time. The youngest team in the program, Chung and Horowitz say they offered "youthful idealism" to other participants. They sometimes wore bear pajamas at conferences and during testing sessions with kids.

During their 12 weeks in Providence, Chung and Horowitz practiced pitching their product, met with potential investors, and improved Jerry the Bear. They pared the lessons Jerry imparted down to basics, focusing on the importance of recognizing symptoms and carbohydrate counting. They made the game more fun and educational, developing a 10-level interactive curriculum and adding a variety of food cards for bananas, cereal, and toast, all of which affect Jerry differently. They narrowed the target age to four to seven.

"The original Jerry wasn't so fun. The entire game was taking care of the bear," says Horowitz. "Now it's a level-based game where the goal is to master the skills. In order to beat the game, you have to master the disease."

Chung and Horowitz are currently working on the eighth iteration of Jerry the Bear, which will feature a touch screen and a link to a mobile application so a parent can monitor a child's progress. The toy will be manufactured in China, and Horowitz will make his first voyage outside the United States this fall to meet with partners in Hong Kong.

Although the operation remains small and Horowitz says they're still "mastering the Excel sheet," there is growth. Orders have started coming in for the $200 bear, and a full launch is planned for summer 2013. In the meantime, Chung and Horowitz are raising a seed round from investors, and the company is eyeing similar products to combat asthma and childhood obesity. Chung was named among the "15 Women to Watch in Tech" by *Inc.* magazine, and Horowitz was invited to give a talk at TEDx Providence.

There have also been some touching moments for Jerry's team. At a children's diabetes conference in Orlando in July, Chung introduced kids to Jerry. A few weeks later, Chung had two envelopes in children's handwriting in her mailbox, both addressed to Jerry the Bear. Both children "told Jerry they missed him, and they couldn't wait to see him again," Chung says. "Moments like those are, without a doubt, the most memorable."

M Sarah Ostman

Q&A

HONORED FOR **TEACHING EXCELLENCE**

At a top research university like Northwestern, it's often professors' research achievements that make headlines. But ask students what inspired them most during their college or graduate school years and most will point to an exceptional class that opened their eyes to a new passion or an outstanding teacher who went above and beyond.

The Charles Deering McCormick Award recognizes faculty members across Northwestern who demonstrate outstanding performance in classroom teaching. Of four such awards given across the University in 2012, two went to McCormick faculty members. ***Bruce Ankenman,*** *associate professor of industrial engineering and management sciences, is a founding faculty member and current codirector of the Segal Design Institute and serves as codirector of McCormick's well-known freshman design course, Design Thinking and Communication. As a researcher, Ankenman develops simple-to-use yet statistically powerful tools for the design and analysis of experiments.* ***John Torkelson,*** *Walter P. Murphy Professor of chemical and biological engineering and of materials science and engineering, has been a faculty member at McCormick since 1983, teaching polymer chemistry, physics and engineering, and heat transfer, and researching polymer properties, processes, and manufacturing.*

McCormick *magazine spoke with Ankenman and Torkelson about their work in the classroom, memorable moments, and advice for the next generation of top teachers.*

McCormick: Bruce, you became a professor after a career in industry. Why did you make the switch?

Ankenman: In the '80s I was a product engineer in the automotive industry. In essence, I spent most of my time collecting data about my product and making decisions about how to improve it. It was difficult at first, and then I realized why: during my entire undergraduate engineering education no one had ever taught me how to collect data and make decisions from it. And I went to a good school! I realized that there was this hole in engineering education, and I thought, I've worked in industry, I know what engineers need. I'm very well suited to fix this problem. Around the same time I came to another realization: I wanted my work to be more personal. I come from a family that worked in medicine, a field that's deeply involved in people's lives. I decided I wanted to have that kind of personal impact in my own career.

McCormick: John, what led you into teaching?

Torkelson: Above all, I knew I wanted to work with students. It wasn't for lack of options. After graduate school I had offers from a national research lab and industrial research laboratories, but I really wanted to have an impact on students, so I chose academia. I came to Northwestern 29 years ago; I defended my thesis on a Wednesday, arrived here on Friday, and started teaching 10 days later. And Northwestern has worked out very well for me. We have excellent students, a collaborative research environment, and great shared facilities, and because of our small class sizes I can really get to know my students.

McCormick: How would you describe your teaching styles?

Ankenman: My style varies depending on the class. For more advanced students, PowerPoint presentations can be very effective. But for introductory-level courses, I prefer the chalkboard, where students can remain engaged and watch problems unfold. Over the years I've picked up a number of techniques to get students interacting, such as breaking them into small discussion groups or posing a problem to the group and asking them to vote on the correct answer. Demonstrations are also fun; I have my Introduction to Statistics students measure the volume of balloons to get them thinking about process output, and I build a discussion about statistical guarantees around how potato chip bags always seem underfilled. Teaching Design Thinking and Communication is also project oriented; students spend the entire first quarter designing devices for people with disabilities. The goal is always to get students to be better decision makers. This also comes through in my tests. I will never ask a question like "Is the target value in the confidence interval?" That's statistics talk. The question will be "Should you sue the potato chip manufacturer for falsely claiming how many chips they gave you?"

Torkelson: I'm also a chalk-and-blackboard instructor. One main characteristic of my classes is that I interact with students and frequently call on them to answer questions. Not only does it help me pick up on students' names, but it ensures they're mentally engaged; I don't want my students to just be stenographers in my class. On occasion I bring something small into class for a demonstration. For example, I bring Silly Putty in to my Intro to Polymers class, and my students enjoy that. I also crack some jokes, mainly at my own

McCormick professors Bruce Ankenman (left) and John Torkelson won two of the University's four Charles Deering McCormick 2012 Awards for teaching.

expense. I'm pretty self-deprecating. My classes are rigorous, but it's always good if students can laugh and smile a little bit, too. And if 99.9 percent of the jokes are directed at me, they don't have to worry about any discomfort associated with that laughter.

McCormick: What have been some of your most memorable moments at McCormick?

Ankenman: My proudest moments are when someone sends me an email three years after graduation and says, "What you taught me helps me in my job every day." That was my goal in leaving industry, after all, to help engineers do a better job of collecting data and analyzing it. Doing well on a test is great, but those emails really make me proud.

There have been some less-than-pleasant memorable moments, too. In Design Thinking and Communication we host guest lecturers once per week for all the sections of the course. On one occasion the lecturer accidentally unplugged the University's computer and set off the security alarm. It was painfully loud, and we could not figure out how to turn it off. But what could we do? We had 250 students in the room, so the lecture had to begin. I stood there with my hand pressed over the alarm trying to muffle the sound for 20 minutes until tech support came and saved us. It was pretty bad.

Torkelson: For me, the most rewarding moments occur when I see a light bulb go off in a student's mind. For a variety of reasons, some students come into my class with a deficiency in their understanding of a subject. After working with them in class or during office hours, I often see that light turn on. After that, things instantly change for them; you really see their confidence grow. That's something I take pride in. I've also had a number of students who have won or been finalists for national research awards or who have gone on to become successful academics themselves. Watching my students become successful is very rewarding. I can't pay back everything I got from my own professors, but helping my students succeed feels like I am paying it forward.

If you were to ask my students about memorable moments in my class, they might have other ideas. For example, I often treat my classes to something I call the "polymer dance" to illustrate the ability of polymer chains to diffuse. The actual dance moves vary. Sometimes it looks akin to a foxtrot, other times it harks back to my days in graduate school on the disco dance floor. In any case, the students are amazed that at my age I still have a lot of flexibility.

McCormick: What advice would you give to someone considering a career in academia?

Ankenman: Get involved in research with a professor—it will really give you a leg up. Nobody really understands what research is until you do it, and research varies heavily from field to field. And to whatever extent you can, try to get practical experience and work that into your teaching. I've found that students respond well to teaching that comes from real-world experience. If they just learn in order to pass a test, it's not going to stick with them as much as when they are learning because they believe they will actually use the material. As a teacher you have to convince them your topic is going to be worth knowing.

Torkelson: Take the time to prepare yourself for the classroom. I think effective teaching requires you to do a few basic things well, and that's about 95 percent of the job. You need to know at the outset what it is you're trying to accomplish in the class as a whole, and then create a logical syllabus so one topic leads to the next. Spend the time each day to be ready to go into the classroom and be effective. That doesn't mean you can't make mistakes. I still do. Of course, I tell the students I don't make mistakes; I tell them every time it looks like I've made a mistake that I'm really just utilizing a pedagogical technique to put them at ease. Above all, remember your audience. It is not your job as a professor to tell people about a subject in the way you currently think about that subject. Your job is to consider at what level your audience is and to challenge them effectively. M

GREENING TRANSPORTATION

One student's whole-brain engineering approach to sustainable transportation policies

Madison Fitzpatrick *comes across as one of those people who could do anything. At 9 years old she took up playing the string bass. At 17 she landed a spot as a chemistry lab assistant at the Georgia Institute of Technology. As an undergraduate she competed as a dancer on Northwestern's Ballroom, Latin, and Swing Thing.*

But with her talent comes a certain shrewdness. That lab assistant gig? She hated it.

"That pure lab science was not for me," she says. "The pace was really slow, and I wanted to do something more applied."

That desire brought her to Northwestern, which had the resources to satisfy both her scientific and artistic needs. After spending a few hours with the course catalog, she chose civil engineering for a major, thinking she might go on to become an architect and have a career where science blends with aesthetics. But when an internship with a civil engineering firm introduced her to the world of transportation, she knew she had found the multifaceted work she craved.

"I realized that only a certain number of people interact with any building, but everyone uses the transportation network," she says. "Transportation involves the community, politics, economics—it's a confluence of different disciplines."

When Fitzpatrick finished her bachelor's degree requirements in three years, her adviser, associate professor of civil and environmental engineering Pablo Durango-Cohen, convinced her to enroll as a graduate student in his research group, where he and his students work on the formulation and analysis of mathematical models to support and improve safety, efficiency, reliability, sustainability, and equity in the provision, management, and operation of transportation infrastructure systems.

"Madison was a sought-after graduate student, and we were lucky her love of transportation and public policy has directed her to our field," Durango-Cohen says.

"I was still having a good time here, and I enjoyed my research, so I decided to stay," Fitzpatrick says. Two years into her graduate work, she spends her days conducting statistical modeling of urban passenger travel. Working with a Chicago Metropolitan Agency for Planning survey of Chicago-area residents, Fitzpatrick is constructing models of when, where, and how people travel. The research builds on similar studies but uses current computing power to produce estimations of more complex, realistic models. Fitzpatrick is applying modeling methods from the social sciences to transportation problems and integrating them with tools to conduct environmental life-cycle assessments of transportation infrastructure and operations.

Durango-Cohen is impressed with her work. "By explaining the relationships between travel outcomes, the proposed models have the potential to provide significantly more accurate representations of travel and to reveal profound and otherwise obscure insights about the synergies that exist among policy alternatives," he says.

Fitzpatrick's ultimate goal is to build a case for transportation policies—including pricing strategies, urban growth boundaries, zoning policies, and urban design guidelines—that could help reduce pollution. About 30 percent of US greenhouse gas emissions come from the transportation sector. "How can we influence people to travel in a sustainable way?" she says. "I'm interested in working with government agencies on new policies."

Too many concepts for promoting sustainable transportation derive from anecdotal and emotional evidence, she says. She hopes her models will prompt policy makers to find new insights in hard data. Yet Fitzpatrick knows that people, not data, change minds. "It's really important that scientists don't get stuck in their labs thinking what they do is really important and failing to communicate what they do to the people who implement policies," she says.

Communication comes easily for Fitzpatrick, whose broad interests have kept her from becoming "a single-faceted scientist."

"In high school I loved physics and calculus, but I also loved literature and world history," she says. "I'm a performer and an organizer. I don't want my professional life to be sitting at a bench by myself in a lab."

She called on her multifaceted skills while a Northwestern undergraduate, serving on the executive committees of her sorority and of the Society of Women Engineers. Now she offsets computer time with dance as a member of Northwestern's Ballroom, Latin, and Swing Thing. She competed with the group as an undergraduate and for the past two years has been a show producer. She also recently took up ballet: "There is so much to think about in terms of your body and the muscles you are using that you can't think about anything else. It's a release." And she still plays bass in the Northwestern Philharmonia.

This year Fitzpatrick also is mentoring high school students in Chicago as part of the National Science Foundation's GK12 fellow program, which partners graduate students with a local classroom. GK12 fellows spend one day a week teaching students and inspiring excitement about science and math. "I hope to be able to tie my research methods and statistical methods into what they do in class," she says. "My goal is to give them a better idea of how science is used in the real world."

Being able to teach others will be a priority whatever Fitzpatrick does in the future, whether she remains in academia, goes into consulting, or pursues another career path. "I really, really care about being a good communicator," she says. "That's a skill that is extremely valuable and not common enough. Communicators are the people who influence lives." **M** Emily Ayshford

Alumni Profile: **Nikhil Sethi**

From undergrad to CEO in two years

It's almost as though Nikhil Sethi ('10) was destined to be a tech entrepreneur. Growing up in the San Francisco Bay area, he watched his father build a flash-memory startup. As a high school student, he developed a software business that allowed novel writers to collaborate.

"Basically, everybody on the block was part of a startup," he says. "I was nurtured in that culture."

So it's no surprise that Sethi heads the most successful startup to come out of McCormick's NUvention: Web course. His company, Adaptly, offers advertising agencies a unified platform to purchase ads across all social networks. Just two years old, it has 60 employees and has raised more than $13 million in funding.

"It's been phenomenal," he said.

Like many great entrepreneurship stories, it almost didn't happen. With an interest in patent law and an electrical engineer for a father, Sethi entered Northwestern in a special program that allows McCormick graduates to proceed directly to Northwestern's law school.

In his electrical engineering classes he learned logic-based reasoning—the ability to understand the nuts and bolts of a problem—but the academic theories were making him feel distanced from the real world and his startup roots. He began spending time at the Kellogg School of Management and eventually teamed up with two MBA students to found Blurtt.com, a service connecting the virtual and the real worlds by allowing users to send real postcards to social media friends. Still weighing whether law school was for him, Sethi also spent time with the school's mock trial team.

Then during his senior year he found out about NUvention: Web, in which students work in multidisciplinary teams to design, build, and ultimately launch software-based businesses. This was the course Sethi had been waiting for: a structured way to find a viable idea and actually bring it to market. He applied at the last minute and was put on a team of five people—two from Kellogg and three from McCormick. During their first meetings he told them about an idea that had been simmering since the summer before, when he had interned at HBO. The channel was launching the show *True Blood* and had to negotiate with several groups to advertise on different social networks.

“I thought, There has got to be a better technology solution to allow a brand to take a message and get it in front of many different people in different social environments quickly,” he says.

The business school students had some reservations: the numbers weren’t there for this kind of business, the market wouldn’t allow for growth, and they didn’t know anything about the advertising space. None of those was a deal breaker for Sethi. He thought he would either go big with the idea or take a job at a major software company.

“The fact that we knew very little about how traditional advertising works has been a big advantage for us,” he says. “If we had listened to the numbers, we wouldn’t be here. But I was passionate about the idea.”

At the end of the course Sethi and Garrett Ullom, a computer science student, headed off to DreamIt Ventures incubator, which gave them $25,000 and offered to teach them a new skill: sales.

“How do you actually go to a customer and sell something?” Sethi said. “That’s an area where we didn’t have any experience.” If it didn’t work out, they thought, Ullom could go back to school and Sethi could find a regular job.

But the momentum didn’t stop. Sethi and Ullom were able to raise another $700,000 in seed money, which got them an office in New York City and enough capital to start working. There were missteps along the way, but the company grew—from 2 people to 5, then to 20, then to 60. Early on Adaptly was able to attract top-tier clients such as PepsiCo, Arby’s, News Corp., Razorfish, and Diageo and has continued that strong growth momentum by working with hundreds more high-profile clients.

While CEO Sethi jets from coast to coast meeting with clients and giving keynotes (calling on the speaking skills he learned back on the mock trial team), he knows he’s still learning to manage a growing company. Next to his bed is a stack of human psychology books.

“This is fundamentally a game of humans,” he says. “It’s optimizing for happiness.” Sethi made an early misstep when, in a cost-saving move, he set up the company in an office that was inside another business. There was no office culture in the shared space. Now, in a new space complete with a cereal bar and with a “happiness manager,” employees are behaving and interacting much differently.

> “In engineering you learn that failure is part of the regimen. There’s always something that will knock you off. Getting back up is the part that’s most important to learn.” NIKHIL SETHI

And after just two years in the business, Sethi’s already giving back as a member of the NUvention: Web advisory board. In the quick-turnaround world of tech startups, he may be the course’s most experienced alumnus.

“I think there’s a lot of knowledge that can be shared, and everything is so fresh in my mind,” he says. “We failed a lot. Advertising, especially, is a roller coaster. It’s always up and down, and it’s easy to fall behind. But in engineering you learn that failure is part of the regimen. There’s always something that will knock you off. Getting back up is the part that’s most important to learn.”

Tapping into alumni knowledge was one of the best skills Sethi learned as an undergraduate. Most students don’t know they can connect with the powerful Northwestern alumni network, he says, but as he was starting Adaptly, he reached out each day to a different alum to ask for a 15-minute coffee meeting. He was never turned down.

Such persistence will help him for the rest of his life.

“If all else fails,” he says, “I’ll do it again.” **M** Emily Ayshford

MCCORMICK IN INDIA

Dean Julio M. Ottino and members of the McCormick community recently traveled to India, a nation with a strong and growing footprint in the engineering sector. The visit was part of McCormick's ongoing effort to engage with its global base of alumni and friends.

The trip began with a visit to IIT Bombay, one of the premier engineering and technology institutions in the country. Ottino represented Northwestern for the signing of a memorandum of understanding between the two institutions, paving the way for future collaborations.

Also representing McCormick on the trip was Vinayak Dravid, McCormick's coordinator of global outreach and Abraham Harris Professor of Materials Science and Engineering, and Kyle Delaney, director of marketing and communications. Northwestern University trustee Bhadrashyam Kothari and the NU Club of India played host to the McCormick visitors.

During their stay, Ottino, Kothari, and Dravid hosted a reception for Northwestern alumni in India and met with several corporate leaders to explore partnerships.

Clockwise, from top left: Northwestern University trustee Bhadrashyam Kothari with Dean Ottino at an alumni reception; Dean Ottino at the Gateway of India; Dean Ottino and IIT Bombay director Devang Khakhar signing a memorandum of understanding; Harsh Sheth and Priyanka Khatri, two organizers of the NU Club of India, with Dean Ottino; Vinayak Dravid, McCormick's coordinator of global outreach, with Northwestern student Arjun Kothari.

Graduate engineering *by the numbers*

1,455 MS APPLICATIONS FOR FALL 2012

711 MS STUDENTS, FALL 2011

820 PHD STUDENTS, FALL 2011

$4,400,000 MURPHY FELLOWSHIPS AWARDED TO FIRST-YEAR PHD STUDENTS FOR TUITION, 2011-12

780 AVERAGE GRE QUANTITATIVE SCORE OF NEW PHD STUDENTS, FALL 2011

3.63 AVERAGE GPA OF NEW PHD STUDENTS, FALL 2011

44% PERCENTAGE OF PHD STUDENTS FROM OUTSIDE THE U.S., FALL 2011

3,150 PHD APPLICATIONS FOR FALL 2012

28% PERCENTAGE OF PHD STUDENTS WHO ARE FEMALE, FALL 2011

83 BS/MS STUDENTS, FALL 2012

$2,477,000 OUTSIDE FELLOWSHIPS FOR GRADUATE STUDENTS, 2011

STUDYING ARCHITECTURE IN BERLIN

Students in McCormick's Architectural Engineering and Design Program traveled to Berlin in September to work in the studio of famed architect David Chipperfield. Here Chanhan Lee (civil engineering '12) talks with managing director Alexander Schwarz about Lee's proposed redesign of a block in Berlin that is a mix of pre- and postwar development, while Larry Booth (seated at left, wearing glasses), Richard C. Halpern/Rise International Distinguished Architect in Residence at McCormick, listens.

Photo: Gordon Welters

CLASS NOTES

1960s

William E. Huxhold ('68), professor of urban planning at the University of Wisconsin–Milwaukee, won the 2012 Education Award of the University Consortium for Geographic Information Science.

1970s

Karla Yale ('70, Kellogg '74) of Indianapolis became a business development partner at Alcova in 2011. Alcova is an operator of 100-acre microorganism farms in Indiana.

Burkhard Fricke (postdoc '72–'73) has been elected vice president of the kuratorium (board) of the Lindau (Germany) Nobel Laureates Meeting, which is attended by 27 Nobel laureates and nearly 600 students. In charge of the scientific program of the meeting, he organizes talks and a panel discussion.

Dwight Grimestad ('74) assumed the new role of vice president of corporate strategy at Archer Daniels Midland Company.

Kevin John Gross ('77), president and CEO of Hillcrest Healthcare Systems, was appointed to the Oklahoma City board of corrections.

David L. Porges ('79), chairman, president, and CEO of EQT Corporation, will be one of the lecturers during "Energy: Who's Got the Power?," a University of Charleston series.

Virginia M. Rometty ('79), CEO of IBM, made *Time*'s list of the world's 100 most influential people and was number one on *Fortune*'s list of the 50 most powerful women in business.

Brian A. Strzalka ('79) has become CEO of ET Technology (Wuxi), a privately held company with locations in China and Germany. It specializes in the design and production of sectional and rolling garage doors and door components.

1980s

Lt. James P. McManamon ('80) has become vice president in the navy and marine corps services sector of General Dynamics Information Technology, based in Fairfax, Virginia.

Michael A. Fitzgibbons ('81) has been promoted to vice president, commercial, of the natural gas gathering and processing business at ONEOK Partners. He had been director of natural gas supply acquisition for the Rocky Mountain region.

Joseph J. Rencis (MS '82) is dean of engineering and the Clay N. Hixson Chair for Engineering Leadership at Tennessee Technological University.

Gloria Grev ('83) of Las Vegas, supervisor of distribution engineering at Southwest Gas Corporation, received the Common Ground Alliance's Ron Olitsky Award in March for her contributions to the damage prevention community.

Lance E. Rosenzweig ('84), founder and CEO of 24/7 Card, was appointed to the board of directors of Quality Systems.

Ruby Rachael Chandy (MS '85) has become president of Pall Industrial.

Mark Iserloth ('85) has joined Mattersight Corporation as vice president and chief financial officer.

Steven McLaughlin ('85) was appointed chair of the School of Electrical and Computer Engineering at the Georgia Institute of Technology.

Kirk D. Bowman ('87), venture partner at Accel Partners, was named to the board of directors of Atlassian.

John G. Lewis ('87) has become CEO of Staging Concepts, headquartered in Minneapolis. It manufactures portable stage, seating riser, and custom railing solutions.

Scott J. Hammack ('88), CEO of Prolexic in Naples, Florida, has been appointed to the Florida Polytechnic University board of trustees.

1990s

Raymond Konopka (MS '90) received Illinois Benedictine College's Alumni Achievement Award in mathematics and computational sciences. His software company helped Disney develop the Fastpass system for its theme parks.

Scott Tanton Allan (MEM '92) has become CEO and president of Hydro Flask, headquartered in Bend, Oregon.

William C. Kircher ('92), previously general manager of Eagle Services Asia, has assumed the newly expanded vice presidency for Singapore overhaul and repair at Pratt & Whitney Global Service Partners.

David Thore Ritland (MEM '92), previously a senior director with Life Fitness, has become president of the Sentral Group, a manufacturer of wire harnesses and cable assemblies.

Mario Greco ('93), senior broker and vice president of sales at Prudential Rubloff Properties, sold more than $115 million worth of residential real estate in 2011, making him the top residential broker in the city of Chicago. He was the Number 6 broker in the entire 64,000-agent Prudential international network.

Matthew Levatich (MEM '94), president and chief operating officer of Harley-Davidson Motor Company, has been elected to the board of directors of Emerson Electric Company.

Mala Nanda (MEM '94) has become vice president and general manager of the Asia Pacific area of Tensar, based in Shanghai.

Smita Shah ('94), president of SPAAN Tech in Chicago, received the Community Service Award from the American Council of Engineering Companies at ACEC's fall 2011 conference in Las Vegas.

Pamay Bassey (MS '95) of Chicago wrote *My 52 Weeks of Worship: Lessons from a Global, Spiritual, Interfaith Journey* (Balboa Press, 2012). The book is based on her 2010 project, "My 52 Weeks of Worship," for which she visited a different place of worship every week.

Michael J. Murphy ('95) has joined Boise Inc. as vice president and treasurer.

Ikhlaq S. Sidhu (PhD '95), previously chief technical officer of Cambria Networks and vice president of 3Com Corporation, has become venture adviser at Onset Ventures.

Andrew Christopher McGeorge (MS '96), formerly senior portfolio strategist with CNBS in Overland Park, Kansas, has become vice president of finance at Service Credit Union in Portsmouth, Maine.

Chelsea R. Stoner ('96) was promoted from principal to partner at Battery Ventures. She is the first female partner in the history of the venture capital firm.

Jose Adrian Bayardo (MEM '98) has become senior vice president of business development for Continental Resources, a petroleum liquids producer headquartered in Oklahoma City.

Kenneth K. Bellaire ('99) was promoted from associate to partner in the global finance practice at Sidley Austin in Chicago.

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Please email your news to magazine@mccormick.northwestern.edu

2000s

Raymond Konopka (MS ’00) of Naperville, Illinois, received an Alumni Achievement Award in mathematics and computational sciences from Benedictine University in February.

Anil Prahlad (MEM ’00) has become chief content officer of RainKing, a solutions provider for technology companies.

Alicia Kenney DiRago (’02), founder and CEO of Whimseybox, a subscription service for craft supplies, was accepted into Chicago business accelerator Excelerate Labs’ 2012 class.

Ritu Singh (’02) of Maineville, Ohio, was promoted to senior associate in the Cincinnati law office of Frost Brown Todd. Her focus is on patent prosecution and application drafting in a variety of arts, including mechanical, electrical, software, and biomedical.

Shawn Wischmeier (MEM ’02) has become chief investment officer for the Margaret A. Cargill Philanthropies, a Minnesota-based organization that combines the assets of three foundations.

Sai Reddy (’03, MS ’04) has assumed a tenure-track faculty position in the Department of Biosystems Science and Engineering at the Swiss Federal Institute of Technology (ETH Zurich).

Beth Lopour (’04) of Los Angeles is investigating epilepsy as a postdoctoral scholar with the Department of Neurobiology at the University of California, Los Angeles. Her husband, **Dan Shrey** (’04), is completing his final year of a pediatric neurology fellowship at UCLA.

Shelby T. Clark (’05) is the founder of RelayRides, a San Francisco–based firm that helps owners rent their private vehicles to neighbors. The firm has annual revenues of $700 million.

Jon Horek (PhD ’06) was a delegate to the 2012 Young Atlanticist Summit, a parallel youth summit to the 2012 NATO Summit in Chicago. Organized by the Atlantic Council and the Chicago Council on Global Affairs, the youth summit allowed about 100 professionals ages 25 to 35 from around the world to meet and discuss current global affairs with world leaders.

Keith Knipling (PhD ’06) received the Presidential Early Career Award for Scientists and Engineers for his research at the Naval Research Laboratory. PECASE is the highest honor bestowed by the US government on scientists and engineers beginning their professional careers.

Rohit Sood (MEM ’06) was named a principal in the Toronto office of McKinsey & Company.

Sotirios Athanasio Tsaftaris (PhD ’06), previously a research assistant professor at Northwestern, has joined the faculty at IMT Lucca in Italy as an assistant professor.

Jorgen Hesselberg (MS ’07) of Arlington Heights, Illinois, was promoted to senior manager of agile enterprise adoption at Nokia. His responsibilities include alignment and adoption of the agile software development method across Nokia, focusing on Berlin, Boston, and Chicago.

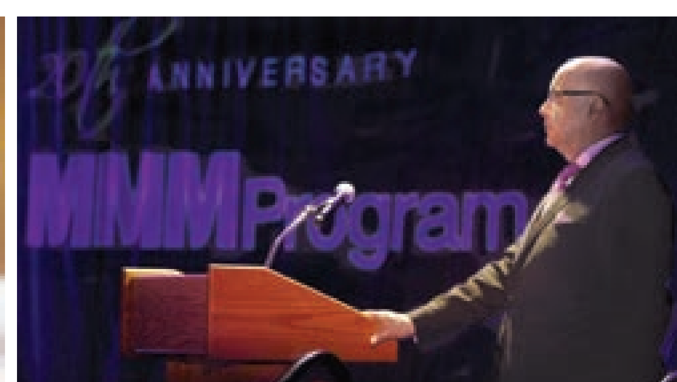
Kelly Koenig Coupe (MS ’08) of Palo Alto, California, was named director of market strategy at the Palo Alto Research Center.

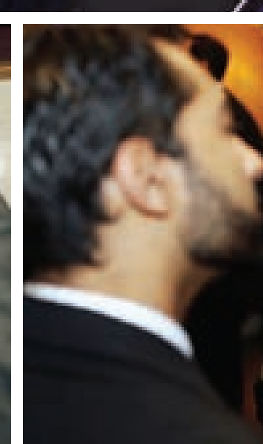
Michael Parrott (’09) has joined Mars & Co., a global management consulting firm specializing in business strategy, as an associate consultant.

MMM ANNIVERSARY

The MMM program celebrated 20 years of visionary education on April 27 at the Evanston Golf Club. More than 180 alumni and friends of the program attended the celebration, which featured a keynote address from Bruce Mau, founder of Bruce Mau Design and a distinguished fellow at McCormick’s Segal Design Institute.

Top row, left to right: Dean Julio Ottino, members of the MMM classes of 2011, 2012, and 2013. Bottom row, left to right: Ernest Wong, Jaymes Hanna, Anand Arivukkarasu, Chris Rosenbaum, and Abayomi Fashoro, all class of 2013; Dean Sally Blount, Kellogg School of Management; left to right, Bruce Mau, Julio Ottino, and Greg Holderfield, MMM codirector; Timothy Hong, class of 2013.





2010s

Mert Hilmi Iseri ('11) and **Yuri Malina** ('12) were granted $50,000 in seed capital from a group of venture capitalists and angel investors to develop SwipeSense, a manufacturer of portable hand-sanitation devices for hospitals. (See story on page 30.)

Marshall Lindsey (PhD '11) has become vice president of strategy and research for Blue Northern Energy, a biodiesel firm in Chicago.

Cassandra Harn (MS '12) of Bozeman, Montana, received a Whitaker International Fellow Grant to Ireland for the coming year.

In Memoriam

Pierce Richardson ('30)
Donald C. McGrane ('33)
W. C. Kunz ('36)
Anthony F. Grande ('37)
Robert E. Osth ('42)
Charles C. Keach ('45)
Hall A. Koontz ('45)
E. Scott Nichols ('45)
Donald A. Anderson ('47)
Ernest E. Carlstrom ('47)
Joseph F. Desmond ('48)
Milbourne E. Lord Jr. ('48)
Joseph T. Wheelock ('48)
Robert E. Boyar ('49)
Robert E. Gustafson ('49)
Carl A. Hermanson ('49)
George W. Knapp ('49)
Glenn F. Park ('49)
William P. Carroll ('50)
Vance H. Pearson ('50)
Paul N. Stevens ('50)

The University community mourned the death this fall of chemical engineering sophomore Harsha Maddula. Nearly 2,000 Northwestern students, faculty, staff, and community members gathered September 28 on Deering Meadow to pay their respects. A resident of the Public Affairs Residential College, Maddula was involved in Engineers for a Sustainable World and other activities at Northwestern. He will be greatly missed.

Craig F. Metheny ('51)
Robert W. Oetjens ('51)
Charles E. Swanson ('51)
John F. Aberson ('52)
Glenn A. Porter ('52)
Lee D. Schmid ('52)
Kenneth J. Eme ('54)
Fred E. Ostrem ('54)
Tung Ming Lee ('55)
Arnold D. Kerr ('56)
Robert L. Guth ('57)
Philip E. Novak ('57)
Edwin J. Nowak ('58)
Charles H. Laws ('59)
Andy V. Ananthakrishnan ('62)
Alan S. Borg ('63)
Harvey A. Brodsky (PhD '65)
Pierre C. Gehlen ('66)
James E. Russell ('66)
Michael G. Kovac (PhD '67)
Samuel W. Beal ('68)
Tewfic H. Toubassi ('68)
Klaus M. Langeneckert (PhD '69)
Theodore M. Thorson Jr. ('70)
Roger W. Vinita ('70)
John W. Caldwell, MD ('71)
William E. Dunn ('72)
Donald L. Haley ('72)
Mrs. James S. Daugherty ('73)
John Chao-Kun Ting (PhD '74)
Paul Nicholas Thielen ('75)
Shailesh H. Patel ('85)
Karen K. Greig (MEM '06)

In Memoriam: **James Farley**

James Farley ('50), an electrical engineering alumnus who turned a small manufacturing company into an international corporation and in retirement used his earnings to better the lives of McCormick students, died August 22 at age 84.

Farley's generosity helped to transform the McCormick School over the past 25 years. The nearly $22 million in donations from Farley and his wife, Nancy, provided the resources for several initiatives that changed the culture of McCormick. Their most generous donation endowed the Farley Center for Entrepreneurship and Innovation, which in the past five years has helped educate hundreds of students and faculty members in the theory and practice of entrepreneurship.

"Jim and Nancy have been continuous investors in innovation and education at McCormick," said Dean Julio M. Ottino (right, shown with Farley). "His contributions and advice have been transformative. He was an original and will be sorely missed."

"Northwestern gave me my start," said Farley, who grew up on a Kansas farm and attended Northwestern with the help of a $75-a-quarter scholarship that paid half his tuition. "It helped finance my education, so I owe a lot to the school."

After Farley graduated in 1950 with a degree in electrical engineering, he served during the Korean War at the White Sands Missile Range in New Mexico. He started his career as a test engineer for General Electric. He then worked as a sales engineer for a Milwaukee motor control manufacturer. In 1960, when he sold a control to the inventor of a new lapping and polishing machine, he joined the inventor's company as a minority investor. The company, SpeedFam, grew rapidly, and Farley was promoted to president. When it was reorganized in 1974, Farley took ownership of the machine-tool side. He continued to serve as president until he was appointed chairman and chief executive officer in 1993. In 1999 SpeedFam International merged with Integrated Process Equipment Corporation to become SpeedFam-IPEC under Farley's leadership. He retired in 2002.

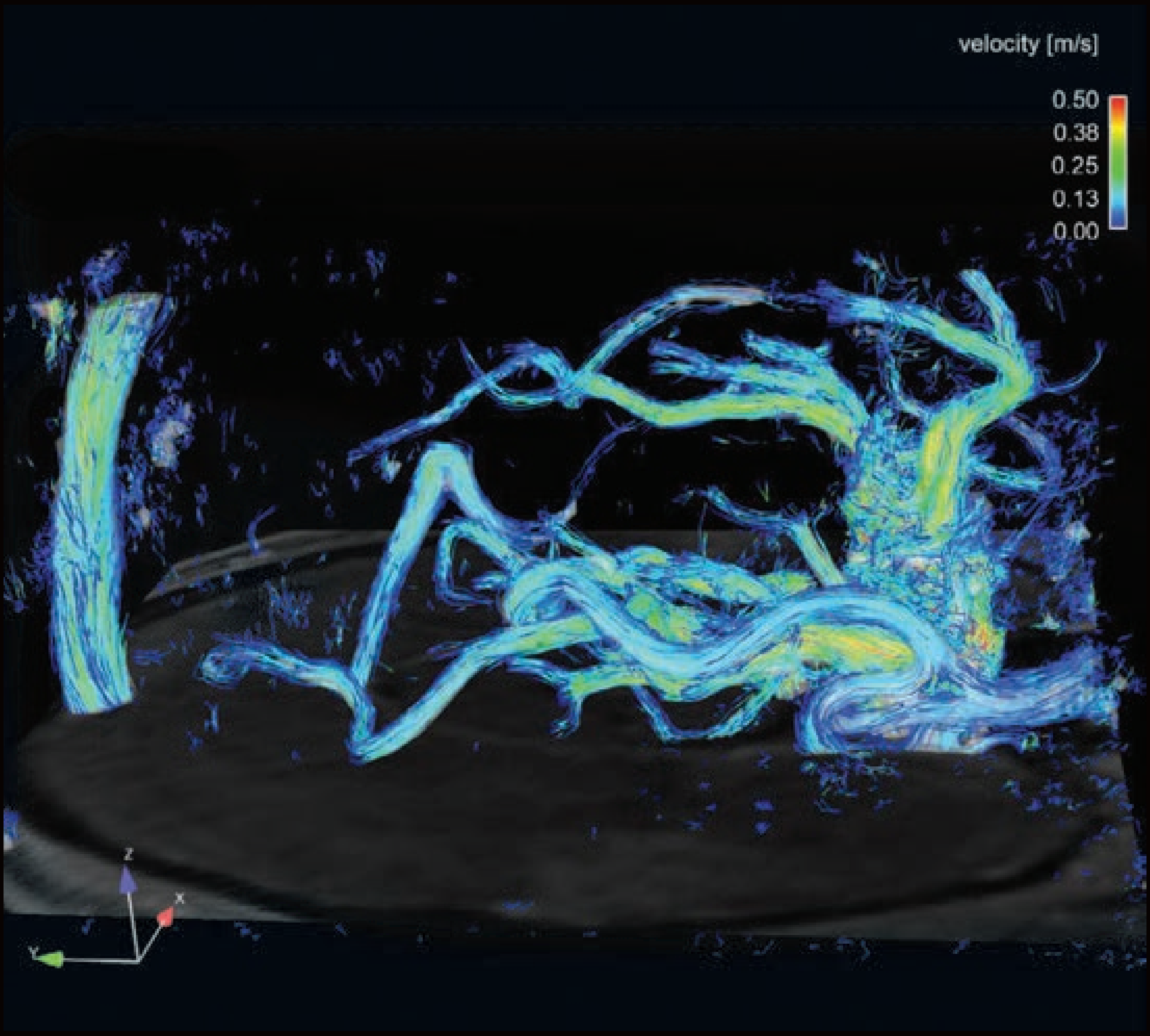
His major donations to McCormick began after he joined the McCormick Advisory Council in 1986. He noticed that the Technological Institute hadn't changed much in 40 years, so he and Nancy ultimately donated money to name a wing of Tech as well as to purchase 10 machines to establish the Undergraduate Machining and Prototype Lab (now in the Ford Motor Company Engineering Design Center). They also endowed a professorship in manufacturing and entrepreneurship.

In 1998 Farley's five children endowed a scholarship in his name. In 2008 the Farleys endowed the Farley Center for Entrepreneurship and Innovation, which has quickly become a focal point for entrepreneurship at Northwestern, particularly with its outreach to the undergraduate population. The center provides several courses and resources for students and faculty interested in entrepreneurship. Its flagship program, NUvention, teaches students from across the University to work in teams and experience the entire innovation life cycle, from ideation to prototyping and business plan development. The center extends its learning opportunities beyond the classroom with space at the Evanston Incubator for student and faculty startups and with the annual Entrepreneur@NU Conference.

"Jim's endowment of the Farley Center helped establish an entrepreneurial ecosystem here at Northwestern that led to *Forbes*'s ranking Northwestern as the most entrepreneurial college in the Midwest this year," said center director Michael Marasco. "Jim took great pride in the fact that his entrepreneurial success could help future generations of Northwestern entrepreneurs. His legacy is realized in every student who participates in a Farley class or program."

"I was an entrepreneur, and we built our company from a dry start," Farley said in 2008. "I've been an entrepreneur interested in entrepreneurship for a long time, so when I heard Northwestern was considering starting this center, I knew it was an area I wanted to support." All engineers have to be entrepreneurial, he said, even if they aren't interested in starting their own businesses. While he always relied on his engineering background, the classes that helped him the most involved business. "You have to speak the language of accounting, whether you're in business for somebody else or for yourself," he said. "If you don't talk the language, you won't get very far. The business side is very, very important."

The Farleys lived in Arizona. James Farley is survived by five children and sixteen grandchildren. His daughter Sarah earned a master's degree in audiology from Northwestern, and his granddaughter Meghan graduated from Weinberg College of Arts and Sciences in 2005. The Northwestern University Alumni Association honored Farley with its Alumni Merit Award in 1996. M



the art of engineering

This image shows the result of 3D visualization of blood flow in the large intracranial vessels in the human head in a patient with an arterioventricular malformation (AVM). The visualization, from the lab of Michael Markl, associate professor of radiology and biomedical engineering, is based on in vivo blood flow velocities, which were measured using 4D flow magnetic resonance imaging, a novel diagnostic imaging technique permitting the acquisition of blood flow with full volumetric coverage of 3D vessel structures inside the human body. The traces represent the 3D path the blood is taking during one cardiac cycle; color coding reflects the local blood velocity. The AVM results in an unusual shortcut between the arterial and venous vessels, resulting in enhanced complexity of the vascular network in the right hemisphere compared with the normal left side.

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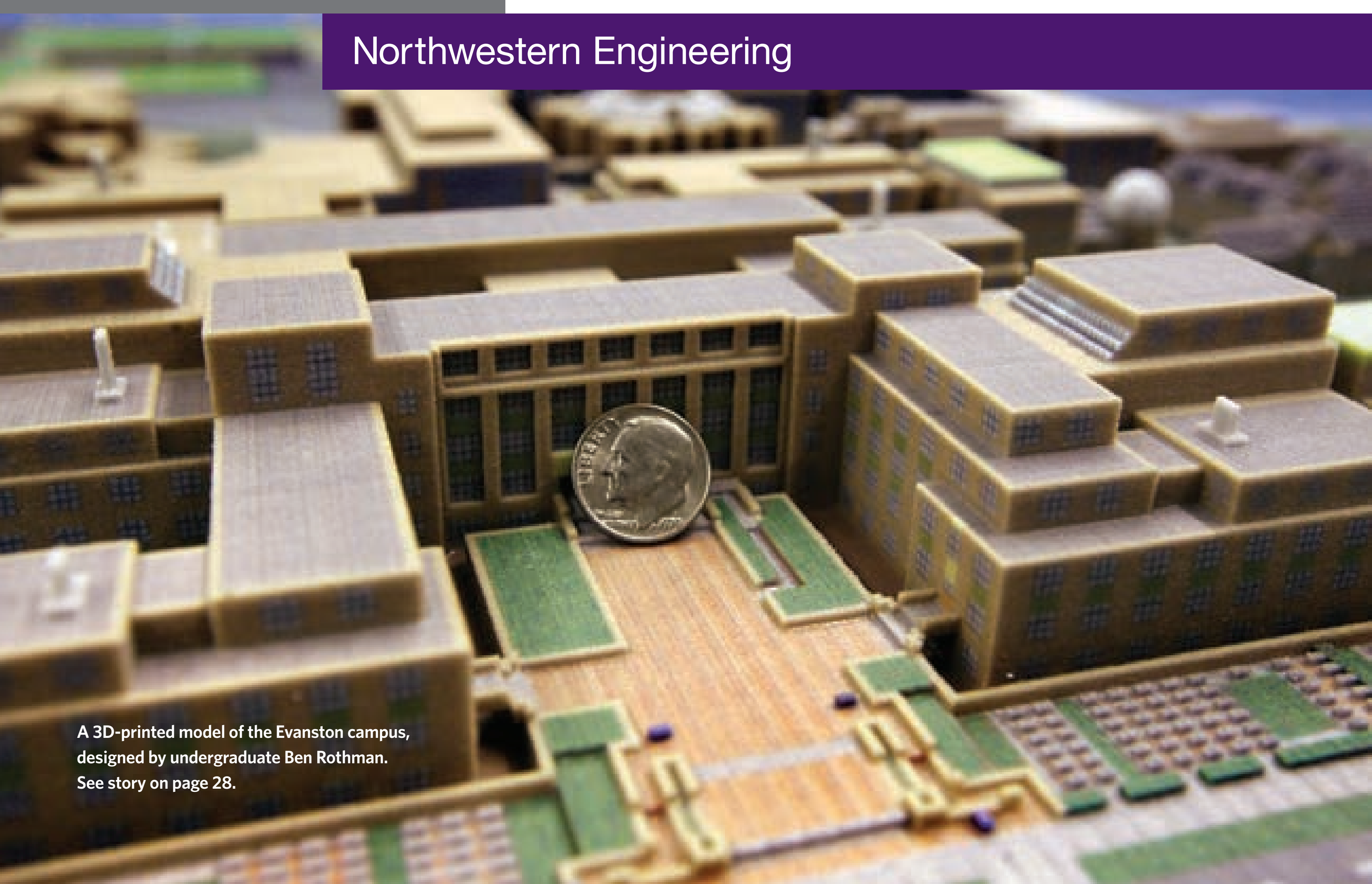

A 3D-printed model of the Evanston campus, designed by undergraduate Ben Rothman. See story on page 28.