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FLY, ROBOT FLY

AN INSECT-SIZE FLIER HAS FINALLY TAKEN WING. CAN RECONNAISSANCE SWARMS BE FAR BEHIND?

THE LADY AND THE LI-ION

POWERING DARWIN'S PARADISE

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IN THE AIR: Wind power is fueling growth in the Galápagos Islands; the sweet smell of success tickles electronic noses; a new light source revives extreme ultraviolet lithography.

CLOCKWISE FROM ABOVE LEFT: SAN CRISTÓBAL WIND PROJECT; MARK HOOPER; WILLIAM COTTON/COLORADO STATE UNIVERSITY

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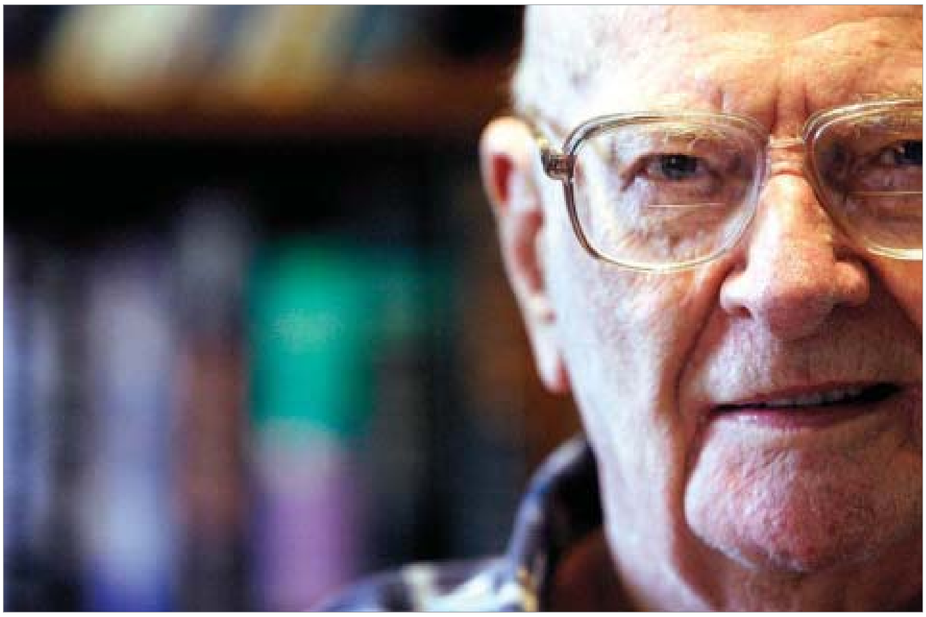

SCIENCE SEER: Sir Arthur C. Clarke looks back on his career.

PHOTOS: LEFT: LUIS ENRIQUE ASCUI/GETTY IMAGES; RIGHT: JACOBS UNIVERSITY

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2008: A SRI LANKAN ODYSSEY

A few weeks after Sir Arthur C. Clarke celebrated his 90th birthday this past December, he received a visit from *IEEE Spectrum* contributor Saswato R. Das. From a hospital bed in Colombo, Sri Lanka, where he was recuperating from a back injury, Clarke talked to Das about his 1945 paper on geostationary satellites; the concept of a space elevator, which he first outlined in his 1979 novel *The Fountains of Paradise*; and his development as a science-fiction writer. Read the article and listen to the interview with this colossus of science fiction.

ONLINE FEATURES:

BUILDING LASERS ON SILICON
Researchers are making big steps toward bonding lasers onto silicon chips to combine the power of microprocessors with light-speed communication.

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MAKING A WORLD OF DIFFERENCE

Members in Ethiopia, Germany, Kurdistan, Pakistan, and Peru are improving communities with projects involving mentoring teachers, search-and-rescue robots [below], a fiber-optic network, and low-cost medical technology.

SUSIE WEE: PICTURE-PERFECT DIGITAL IMAGES

Read why *Computerworld* magazine says Wee's work in imaging makes her one of "40 under 40" IT innovators to watch in coming years.

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back story

Of Giant Tortoises and Men

THE GALÁPAGOS Islands, a cherished haven for nature lovers and a rarefied ecosystem where Charles Darwin drew inspiration for his theory of evolution, is not the place you'd expect to find a multimillion-dollar cutting-edge engineering project.

So when *IEEE Spectrum* Associate Editor Erico Guizzo learned that the Ecuadorian government, with help from the United Nations and an international consortium of utility companies, planned to build three massive wind turbines on San Cristóbal, the Galápagos's easternmost island, his first thought was: This I have to see.

Guizzo contacted the organizers of the project, and late last year he found himself on a 32-hour-long journey—involving three planes, two taxis, one bus, and a three-and-a-half-hour open-ocean boat ride—to reach the archipelago, some 1000 kilometers from mainland Ecuador.

"It was really tiring, but when I saw San Cristóbal emerging on the hazy horizon, I knew this was a special place," Guizzo says. "And I can attest to its remoteness!"

On the island, he watched a team of engineers struggle to get the three 800-kilowatt turbines into operation. He also learned about the many other challenges the project faced as part of an effort to free the Galápagos from fossil fuels. [See Guizzo's full account, "Wind Power in Paradise," in this issue.]

Guizzo also took some time to check out the local wildlife, including the famed giant tortoises [see photo]. "You can't help feeling a bit like Darwin when you walk around this place and marvel at these other-worldly creatures," he says.

But as Darwin noted more than 170 years ago, the uniqueness of the archipelago's ecosystem means it's also extremely fragile. The survival of its distinctive plants and animals, many of which are endangered, now depends on finding ways to protect them from foreign species—including us. ❑

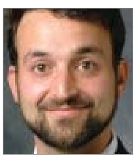
CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, the first Update page is in *IEEE Spectrum*, Vol. 45, no. 3 (INT), March 2008, p. 9, or in *IEEE Spectrum*, Vol. 45, no. 3 (NA), March 2008, p. 11.

ERICO GUIZZO

contributors

JOSEPHINE B. CHANG is coauthor of "Electronic Noses Sniff Success" [p. 48], which describes the advances in printed electronics that will finally make e-noses cheap and portable. Chang researched printed electronics at the University of California, Berkeley. She now works with silicon semiconductors at the IBM Thomas J. Watson Research Center, in Yorktown Heights, N.Y.



GREG LINDEN lives in Seattle and works at Microsoft Live Labs. In 2004, he formed Findory.com, which sought to personalize the flow of information. He worked at Amazon.com from 1997 to 2002, first writing its recommendation engine and then leading the software team that developed Amazon's personalization systems. Linden makes the case for recommender systems in "People Who Read This Article Also Read…" [p. 42].

JAMES OBERG, a 22-year veteran of NASA mission control, is a writer and consultant based in Houston. His latest book, *Star-Crossed Orbits: Inside the U.S./Russian Space Alliance* (McGraw-Hill, 2002), describes the development of the International Space Station and the Russians' role in making it possible. This month Oberg weighs in on a new book on *Buran,* the Soviet space shuttle [p. 18], which made its first and only flight in 1988.

DAN SAELINGER, who shot the photos for "Fly, Robot Fly" [p. 21], says, "As soon as I heard the words *robot fly* I knew I wanted to be involved in this project. I kept imagining a radio-controlled car remote giving directions to this tiny fly. I mean, how do they even make something so small tick?"

VIVEK SUBRAMANIAN, an IEEE member, is coauthor of this month's feature on electronic noses [p. 48] and an associate professor of electrical engineering and computer sciences at Berkeley. He cofounded Matrix Semiconductor in 1998.

KIRK TESKA, who teaches at Suffolk University Law School, in Boston, is the managing partner of Iandiorio & Teska, an intellectual property law firm in Waltham, Mass. He is the author of the book *Patent Savvy for Managers* (Nolo, 2007). For this month's Invention [p. 20] he tackles the issue of software protection.

ROBERT WOOD, author of "Fly, Robot Fly," is an assistant professor of electrical engineering at Harvard and principal investigator at the Harvard Microrobotics Laboratory. When not tinkering with robot flies, his group investigates the development of other "species" of arthropod-inspired robots. Look for Wood's robotic flies in New York's Museum of Modern Art this spring.

CLOCKWISE FROM TOP LEFT: JOSEPHINE CHANG; TRACY SAELINGER; PEG SKORPINSKI; H ALEX HARRISON; ELIZA GRINNELL; JAMES OBERG; GREG LINDEN

The hope is to build robotic flies that could work in any situation in which it would be better or safer to send them instead of humans

spectral lines

LUCIEN BULL demonstrates the high-speed camera he invented in 1903, the first to record insect flight.
PHOTO: NMEM/SCIENCE & SOCIETY

Winged Victory: Fly-Size Wing Flapper Lifts Off

DESPITE THE fact that we'd likely drown in our own waste if it weren't for their enormous fondness for eating our garbage and excrement, flies don't get any respect. Not from most of us anyway, who see only pests and disease vectors as we swat with abandon whenever they're around.

But there are a few good scientists and engineers who reach for their notebooks and video cameras instead, amazed and astounded by flies' aeronautic wizardry. With a brain that's home to several hundred thousand neurons—we each house 100 billion in ours—a fly can duck, dive, hover, rotate, and fly with easy accuracy and endurance, despite having a lousy field of vision and a carb-based Dumpster diet for fuel.

One of the fly-enamored among us is Harvard University's Robert Wood, author of this issue's "Fly, Robot Fly," in which he recounts efforts to build tiny flying robots based on the fly's native wing-flapping skills. His own robotic fly, at 60 milligrams about the size of a chubby real fly, is the first of this robot class to become airborne.

The scientific study of insect flight has its roots in the second half of the 19th century. Queen Victoria was on the throne, technological innovation was in high gear, and the Industrial Revolution careered along with it. Natural history and flora and fauna worship were all the rage—although they would soon give way to more empirical disciplines like physics and science-based medicine—and museums and societies sprang up to serve this public interest.

Photography had also permeated the 19th-century zeitgeist. British-born Eadweard J. Muybridge became the first to isolate locomotion in his famous stop-action studies of humans and animals. Meanwhile, in France, physiologist, inventor, and chronophotographer Étienne-Jules Marey, who discovered that insect wings carve figure eights during movement, was inventing cameras and devising experiments to tease out the details of bird and insect flight. Some years later, his assistant and successor Lucien Bull invented the stereoscopic spark-drum camera, which took pictures at up to 2000 frames per second. Bull used his invention to make the first-ever movies of insect flight (go to http://www.expo-marey.com/indexFR.htm to see examples of their work).

Fast-forward to the late 20th century: the world went digital and cameras and experimental methods improved significantly, but questions about how flapping-wing flight works at fly scales remained essentially wide open.

Then in the 1980s and '90s, an eclectic and far-flung cohort of researchers, among them Charles Ellington from Cambridge University, Michael Dickinson, now at Caltech, and Ronald Fearing from the University of California, Berkeley, set out to describe the kinetics of insect flight. Through ingenious experiments with live insects and dynamically scaled-up insect models, they managed to pin down some of the major mechanisms and physical forces that propel a fly through its airspace.

Now the hope is to use that know-how to build better houseflies: inexpensive, tiny robot flies that could work together, lots of them, on search-and-rescue missions, environmental monitoring, planetary exploration, military surveillance, and in virtually any situation in which it would be better or safer to send a batch of robotic flies instead of humans.

Professor Wood's accomplishment is remarkable, but much remains to be done before you'll see robotic flies buzzing over a fire or monitoring tornado damage in your neighborhood. Small doesn't mean simple. The obstacles facing tiny robots' flying and working in uncontrolled environments are as daunting as those faced by your pet AIBO. But as is often noted, flies have had a hundred million years or so to work out the kinks in their evolutionary flight plans. Perhaps in another 10 we'll be able to say the same about their electronic counterparts.

—SUSAN HASSLER

forum

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THE TRUTH BEHIND THE NUMBERS

"Greenhouse-Gas Trends" [The Data, January] states that Europe decreased greenhouse-gas emissions from 1990 to 2005 while the United States increased emissions. This ignores the very reason that 1990 was chosen as the baseline year for the U.S.-rejected Kyoto Protocol.

In 1990, at the time of the fall of the Berlin Wall, Europe knew that bringing the former Eastern bloc countries up to Western European standards would result in a huge decrease in all sorts of pollutants from the very dirty smokestack industries prevalent during the Soviet era. If you discount that cleanup, it is a sure bet that Europe as a whole would have had a net increase in greenhouse-gas emissions over the same time period.

Ken Javor
IEEE Member
Huntsville, Ala.

EVALUATING CARBON CLEANUP

William Sweet's article, "Restoring Coal's Sheen" [January], missed a question critical to cleaning up the burning of fossil fuels—namely, what is the overall energy balance for the process described in the article? Every scheme needs to look at the total impact on cycle (fuel-to-electricity) conversion efficiency. If you start with a coal-fired plant and add an air-separator plant on the front end, flue-gas recycling fans and two sets of cooler/condenser systems in the middle, and a CO_2 gas-to-liquid compressor system on the back end, and then truck the liquid CO_2 somewhere off-site and pump it into the ground, what is the resultant "womb to tomb" efficiency of the process in kilowatts per hour?

John Spencer
IEEE Senior Member
Oreana, Ill.

William Sweet responds: The total system energy balance—together with economic and carbon balances—is among the key issues to be evaluated at the Schwarze Pumpe demonstration plant. The energy costs associated with the oxygen-nitrogen separation system are especially high, and Vattenfall considers it crucial to get those costs down in future oxyfuel plants. With the U.S. Department of Energy's cancellation of the FutureGen project—a big coal-gasification plant that would have generated electricity and yielded hydrogen, with the carbon dioxide captured and stored—Schwarze Pumpe is more than ever the only game in town. Vattenfall and Alstom Power are to be commended because this will be the first larger-than-laboratory-scale plant to evaluate all aspects of capturing and sequestering CO_2 using the oxyfuel process.

IS JOURNAL PUBLICATION OBSOLETE?

Robert W. Lucky's "Technical Publications and the Internet" [Reflections, January] raises an important issue. Today the information in scientific and professional journals can be submitted and transmitted electronically; the Internet makes printing and shipping journal copies obsolete. The true function of a refereed journal, then, is to filter information through a committee of recognized experts. However, journal publication is likely to reduce the number of people who will see your work.

Much scientific work is now interdisciplinary, so you really need many subscriptions. You cannot very well subscribe to a dozen expensive journals. If you have a sufficiently large library nearby, you must go there once a week or so. At some point you may simply give up—and miss an important new paper. Further, copyright restrictions prevent your reading the full text of most papers on the Internet. Societies like the IEEE offer publications on the Web, but they charge fees affordable only by large libraries or businesses.

This problem can be solved neatly. All we need are the editorial committees—those of currently existing journals will do nicely—and Web pages. Members of the vital expert editorial committees normally don't charge for their services. The small cost of a Web page and a webmaster would be no problem for libraries and professional societies. Libraries would save hugely on subscriptions and storage space. Everybody would benefit.

Granino A. Korn *IEEE Fellow, Chelan, Wash.*

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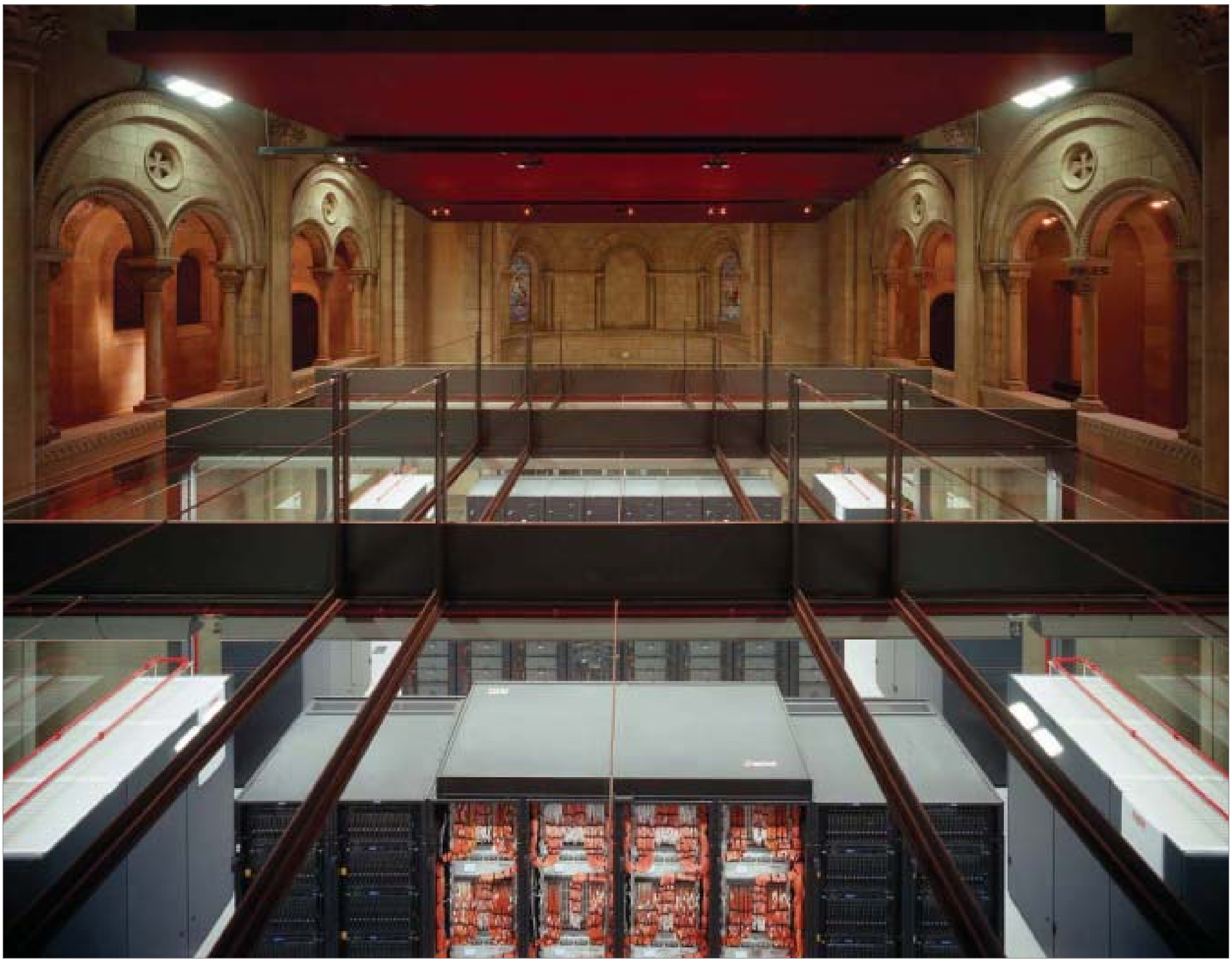

MODERN GOTHIC: MareNostrum's 10 000 processors will be key to figuring out how to program processors with hundreds of cores.

PHOTO: ROLAND HALBE/ BARCELONA SUPERCOMPUTING CENTER

The Church of Microsoft

The software maker tries to get ahead of the move to hundreds of processor cores per chip in a deal with the MareNostrum supercomputer

The IBM MareNostrum supercomputer sits in a Gothic-style chapel on the outskirts of Barcelona, Spain. It may not be the world's fastest—although it is in the top 20—but it is certainly the world's most beautiful computing machine [see "Solving the Oil Equation," January]. And if all goes according to plan, this is where future generations of Microsoft's Windows operating system will be born.

For Microsoft, MareNostrum's more than 10 000 IBM microprocessors and 20 terabytes of memory are the ideal testing ground for the software that will run the kind of multicore and many-core microprocessors that will hit our desktops in the next few years. Those CPUs are expected to be made up of hundreds of processor cores, so it takes a supercomputer with thousands of processors to simulate them for software development. Which is why Microsoft and the Barcelona Supercomputing Center, which runs the MareNostrum, struck a deal in late January to form a joint research center dedicated to solving the vast array of problems associated with programming for multicore processors.

To make ever more powerful processors, the chip industry once relied on simply shrinking

update

a single processor core and ramping up its clock speed. But a few years into the new century, it became clear that this was a dead end: performance was not improving fast enough, while power consumption was accelerating out of control. The solution was to put more than one processor on the same chip and run them both at moderate speeds.

Two- and four-core processors are common now. “We know how to use these,” says Andrew Herbert, managing director of the Microsoft Research Laboratory in Cambridge, England. The question is how to make the best use of the hundreds of cores that will appear on chips in the next 10 years. Microsoft hopes to find out by simulating the problem and various solutions on the MareNostrum.

For decades, computer languages have been conceived and designed with the expectation that a sequence of instructions will be executed essentially one after another. This approach makes sense when a calculation is carried out on a single microprocessor. But when there are 100 processors, how should this sequence be divided up? Answering that question is at the heart of the joint research center’s mission. “There are lots of good ideas out there which we want to explore,” says Herbert.

In some cases, it’s easy to see how the work can be divided, says Tim Harris, a computer scientist at Microsoft Research who is involved in the MareNostrum collaboration. For example, when rendering a scene from a computer game, the instructions can be easily divided among cores by giving each a portion of the scene to be rendered.

With other tasks, things aren’t so straightforward. One problem is how to give parallel computations access to shared data without them all trying to access the same chunk of information at the same time.

The conventional solution is to lock the memory so that only one computational thread has access to it at a time. But lock-based programming is notoriously hard to do in practice and can cause bottlenecks.

To cope with this problem, one of the ideas Microsoft is testing in Barcelona is transactional memory, which allows free-for-all access to shared memory in the hope that each thread will want different pieces of data. If a conflict arises, the transactions involved are halted and started again. “This is one of the hot topics in parallel computing,” says Harris.

Transactional memory can be built into the hardware. Indeed, at February’s IEEE International Solid State Circuits Conference in San Francisco, Sun Microsystems reported the first server processor utilizing a type of hardware-enabled transactional memory. Sun’s move is the kind of thing Microsoft may want to see more of. One of the goals of the MareNostrum project is to “explore a top-down approach in which the software requirements determine the hardware architecture rather than the other way round,” says Herbert.

Such an approach could lead to some radical departures in design, says David Patterson, an IEEE Fellow and expert on parallel computing at the University of California, Berkeley (who is not involved in the collaboration). He suggests using cores with different architectures on the same chip. “It may be that one type of architecture is best for speech recognition and another for image processing,” he says.

At this point, almost any idea can be entertained, and Microsoft will surely try many of them. The next few years are “a rare opportunity to reinvent computing entirely,” says Patterson.

—Justin Mullins

NASA

DUST-DEVIL DYNAMO

Researchers at the University of Michigan in Ann Arbor showed that natural electric fields as strong as 160 kilovolts per meter play a role in determining the amount of dust that makes it into the atmosphere, where it can influence weather and climate. Electric charge reduces the amount of wind needed to blow sand around and can directly lift dust off the ground. Scientists first noticed electricity’s influence when examining dust devils in the desert but had to develop a new kind of electric field analyzer to quantify it.

More at http://www.spectrum.ieee.org/mar08/dynamo

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410 GHz

A new record frequency for a CMOS oscillator and antenna. Researchers from the University of Florida, in Gainesville, reported more than doubling last year's record. The achievement may lead to cheap terahertz security cameras that can see through clothes and packages.

Silicon Slivers for Flexible Circuits

Printing CMOS on plastic

SILICON CIRCUITS that bend and stretch recently took an important step away from the world of science-fiction novels and Hollywood movies toward the real world of medical devices and media players.

A team of researchers at the University of Illinois at Urbana-Champaign (UIUC) says it has printed silicon circuits onto plastic in the form of the same CMOS circuits that dominate digital logic today. The breakthrough brings researchers closer to printing circuits on plastic that approach the performance and reliability of silicon chips.

The team, led by materials science and chemistry professor John A. Rogers, had earlier shown that they could form circuits by transferring thin ribbons of silicon onto glue-coated plastic using a patterned rubber stamp. But the resulting devices used only *n*-type silicon, whereas CMOS logic has both *n*-type and *p*-type. CMOS circuits are generally more power-efficient, because current should flow through them only when their bits are flipping. In any portable electronic device, that means longer battery life. But in the case of plastic electronics, CMOS is even more important, because it reduces the amount of heat produced—which, left unchecked, could melt the plastic.

Rogers's research, which was reported in January in *IEEE Electron Device Letters*, also showed that printed plastic circuits can reach speeds matching those of silicon chips. Rogers says his group has built silicon circuits on plastic that switch at about 500 megahertz, five times as fast as the clock in a 1995 Pentium microprocessor. "And there's no fundamental reason you couldn't go much higher," he says.

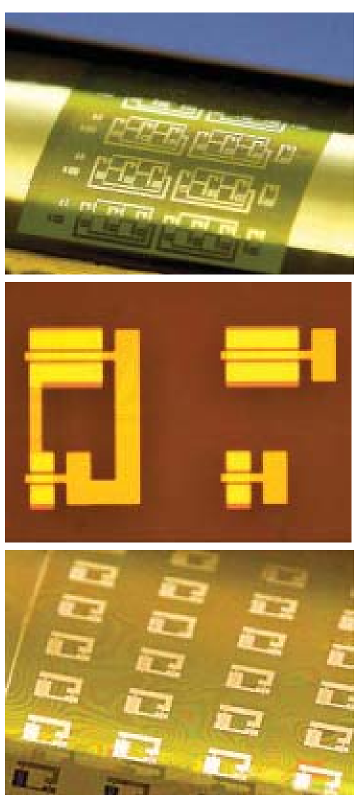
The speed of these circuits greatly outstrips those made using organic semiconductors, a key competitor in the plastic electronics race. The main problem of organics is inherently low charge-carrier mobility, the metric describing the speed at which charges move through a material. The best organics have mobilities of about 1 square centimeter per volt second versus 85 cm^2/Vs for Rogers's CMOS circuits.

The UIUC group's technology also competes with plastic circuits made from semiconductor nanowires, such as those under development at Palo Alto, Calif.–based Nanosys. Instead of etching off ribbons of semiconductor from a wafer as the Illinois group does, Nanosys and its partners chemically synthesize silicon nanowires by means of vapor deposition.

The UIUC and Nanosys approaches "are similar conceptually in that they take advantage of the fact that single-crystal silicon is a good material for charge transport compared with, say, organics," says Rogers. "And they both use silicon structures small enough so that they are flexible and can be integrated with plastic." But Rogers is convinced that making your own silicon when high-quality wafers are commercially available adds an unnecessary complication to the manufacturing process. Citing confidentiality agreements with Nanosys's commercial partners, the company's cofounder and vice president of business development, Stephen Empedocles, declined to make direct comparisons between the Nanosys and UIUC approaches.

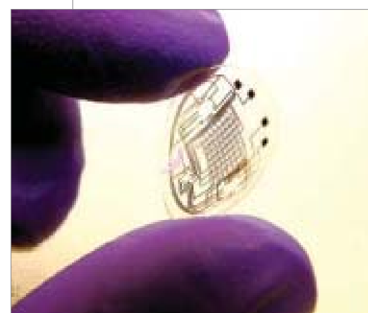
Rogers's technology is under development at Semprius, a start-up based in Durham, N.C., of which he is cofounder. Besides refining the manufacturing process, Semprius is working on making silicon-based electronics that are not only bendable but stretchable. That involves making the silicon thin and then structuring "the material into a wavy shape so it becomes like the bellows on an accordion," says Rogers. One application the company is investigating is putting the stretchy circuits on spheres for electronic eye-type imaging systems.

—WILLIE D. JONES



PLASTIC POWER: Ring oscillators [top] and inverter circuits [center and bottom] made of silicon ribbons printed on plastic.

PHOTOS: JOHN A. ROGERS/UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN



news brief

EYE-PODS

Researchers at the University of Washington–Seattle and at Sandia National Laboratories, in Albuquerque, have unveiled the latest advance in head-up displays: a contact lens with an imprinted electronic circuit and red LEDs. Future versions will superimpose images over the user's view of the world and include wireless transceivers for two-way communication and solar cells for power. Now what's to stop future generations of students from furtively scanning crib sheets when the illicit notes are on displays built into their contact lenses?

PHOTO: UNIVERSITY OF WASHINGTON-SEATTLE

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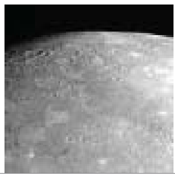

3.5 BILLION KILOMETERS The distance the *Messenger* spacecraft had to fly to get this image of Mercury [see "A Messenger Arrives at Mercury," *IEEE Spectrum*, December 2007]. Features seen in *Messenger*'s photos lend weight to the theory that Mercury is shrinking as it cools. PHOTO: NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/CARNEGIE INSTITUTION OF WASHINGTON

update

A New Light Source for EUV Lithography

Extreme ultraviolet laser offers a new route to next-gen chips

LIGHTING THE WAY: A new tabletop extreme ultraviolet laser.
PHOTO: WILLIAM COTTON/COLORADO STATE UNIVERSITY

A NEW TYPE of X-ray laser could give hope to the semiconductor industry as it struggles to continue its march toward miniaturization. This next-generation chip-making tool was developed at the National Science Foundation's Engineering Research Center for Extreme Ultraviolet Science and Technology, located at Colorado State University, in Fort Collins.

The laser operates at wavelengths of 18.9 and 13.9 nanometers, the latter fine enough for extreme ultraviolet (EUV) lithography, which will be needed to manufacture the generation of chips that are to become available around 2011. The Colorado team found a way to take a small "seed" of EUV light, also called soft X-rays, and amplify the seed to produce a beam 400 times as intense. Finding a suitable light source for EUV lithography machines has proved much more difficult than expected, and though the Colorado laser is not yet powerful enough to replace the light sources already in development, its tabletop size and optical quality could accelerate the development of EUV components and materials.

The Colorado group, led by IEEE Fellow Jorge Rocca, generated low-energy seed pulses of EUV light by firing a titanium-sapphire laser through a neon-gas cell. The interaction between the laser and the neon generated harmonics—low-energy laser light at multiples of the original laser's frequency. The harmonics were fed to an amplifier, which is really a plasma made by irradiating polished molybdenum or silver slabs with pulses from another laser. The amplifier boosts the power only of the desired wavelengths. Molybdenum amplified the 18.9-nm wavelength, and silver boosted the 13.9-nm wavelength required for EUV.

Chip makers will begin to need EUV for state-of-the-art chips by 2011 or 2012, when the features that make up transistors must be just 22 nm. On most advanced chips today, they are 65 or 45 nm.

The chief challenge in getting EUV lithography ready for its debut has been the light sources [see "Plans for Next-Gen Chips Imperiled," *IEEE Spectrum*, August 2007]. At the moment, the leading light sources generate EUV light by blasting droplets of tin with kilowatt-class carbon-dioxide lasers. The tin becomes a plasma and reradiates some of the laser's energy at 13.5 nm. Cymer, of San Diego, Calif., recently reported reaching a record 100 watts of light using that process, but only in short bursts.

The problem with the existing EUV sources is that the light produced is not coherent—that is, its waves are not all in phase with one another, according to Stefan Wurm, who manages extreme ultraviolet strategy at Sematech, the independent, nonprofit semiconductor industry consortium responsible for helping the industry develop new chip-making technologies. Coherent light is better for most applications. "You reduce power if you turn incoherent sources into coherent sources by filtering," says Wurm. And the lower the power, the longer it takes to form patterns on a chip.

"The most important aspect of this work is the demonstration of an almost fully coherent soft X-ray laser," says Rocca, head of the Colorado team. "Coherent soft X-ray light can be used to measure the properties of materials and directly write patterns with nanoscale dimensions. It can also be used to look for extremely small defects in the masks that will be used to print the future generations of semiconductor chips."

The new EUV lasers demonstrated by Rocca's group will prove valuable to semiconductor industry research right away, predicts Wurm. In particular, he thinks they'll be used in developing and testing photoresists—the polymers that harden when exposed to light, thus capturing the light's pattern on the chip. If chemists can reduce the amount of energy needed to set resists, then EUV-light-source makers have an easier goal to attain for the power level of their sources.

The logical next step is to increase the energy of the output pulses by increasing the energy of the seed pulse and the volume of the amplifier, Rocca says. "More power will make the lasers easier to use."

—SASWATO R. DAS

commentary

JUNJI KUROKAWA/AP PHOTO

Blu-ray's Empty Victory

HD-DVD is beaten, but online movie rentals and the humble hard drive may claim the spoils

By Steven Cherry

By now you've probably heard the biggest news to come out of January's Consumer Electronics Show (CES): Sony's Blu-ray has beaten Toshiba's HD-DVD in the high-definition DVD war. Yet the real winner may be Apple. Or Netflix. Or Comcast.

Until January, the major movie studios were evenly divided between the two formats. But then Time Warner, which had supported both, announced at CES, in Las Vegas, that it would no longer release its movies in HD-DVD. In Hollywood, where the line between perception and reality can be thinner than a laser beam, this was taken as a complete victory for Blu-ray and, therefore, it was one.

It's the very skinniness of blue lasers, thinner than red, that lets blue lasers read data when it's packed five times as densely as it is on today's CDs and DVDs. Both Sony and Toshiba used this one scientific principle, yet they created different and incompatible formats. The incompatibility has frustrated movie studios and electronics manufacturers alike, which have watched consumers sit on the sidelines, uncertain what disks—and players—to buy. Having sold us VHS tapes and then DVDs, studios and manufacturers hope that now that Blu-ray has come out on top, we will buy our movie collections for a third time.

But there's every reason to think that Sony's victory will be for naught. Many of us won't rebuild our video collections yet again, and if we do, it won't be with thin little platters. We'll simply download movies through our DSL and cable modems.

That might not have been apparent when Sony and Toshiba began work on next-generation DVDs back in the 1990s, a time when broadband was rare and slow. As late as 2000, when Sony showed its first prototype Blu-ray players, broadband penetration rates, including Japan's and the United States', were under 5 percent. Counting on consumers to download movies was unrealistic.

Today, however, throughout the developed world, broadband is used in at least half of all households. And while a high-def movie can take an hour to download even on a fast DSL connection, you can start watching within a minute; the data flow continues in the background.

And so when you look past the Blu-ray victory, the latest developments in digital movies are all about downloads, not disks.

At MacWorld, which directly followed CES, Steve Jobs announced a new download service for renting movies. As with music, Apple has struck deals with the major movie studios. You can begin a show on your computer or television and finish watching it on your iPod or iPhone. The service started in February with 1000 movies, costing US $2.99 to $3.99 each.

Apple's biggest competitor may be Netflix, which has deals with all the same studios. Subscribers can view hours and hours of movies without paying anything more than their current monthly subscriptions. Netflix relaunched the service in January with more than 6000 titles.

Back in February 2007, TiVo and Amazon started a movie partnership that lets you buy or rent movies, which get stored on your TiVo's hard disk. A review by the Web magazine *Engadget* said, "If you already own a TiVo, then this is about as easy as movie downloading can get."

Older download services are still around, such as Movielink, Vudu, and CinemaNow, which lets you buy some first-run movies, starting at $14.95, while they're still in theaters.

Finally, at CES, Panasonic and Comcast showed a portable digital-video recorder with its own screen. At home, it's like any DVR you might get from your cable company. But when you and the family go on vacation, just pull it out of its docking station. It comes with a 12-volt car adapter, so the kids can watch in the backseat and at the summer cottage.

So do we really need to trudge out to Blockbuster, Best Buy, or Wal-Mart for a disk? Or wait for the now-familiar red envelope from Netflix? A lot of companies, including Apple and Netflix itself, are betting no. Sony and the other movie studios, even though they get a cut from movie downloads, hope the competition is wrong. I don't think they are. ❑

the big picture

EYE CANDY
No, this is not the electronic version of Candy Land. It's the latest element in the U.S. Global Positioning System, deployed on 2 January. Built by Lockheed Martin for the U.S. Air Force, the satellite payload has enhanced signal power and two military and two civilian signals. Ideally, it can pinpoint locations down to less than 1 meter. The tall candy-cane antennas handle UHF links to the ground; the squat Popsicle antennas, satellite-to-satellite UHF connections. The antenna cones are for the L band, a portion of the spectrum reserved mainly for military telemetry and geopositioning communications.

PHOTO: LOCKHEED MARTIN CORP.

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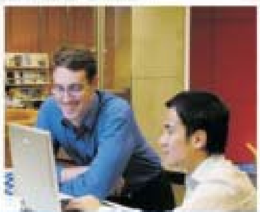
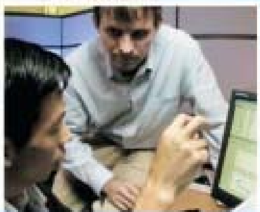
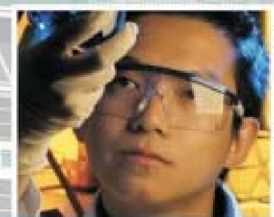
A*STAR INVESTIGATORSHIPS



Prestigious Research Award for young scientists and engineers

Starting 2008, the Singapore Agency for Science, Technology & Research (A*STAR) will bring together 6 physical science and engineering research institutes to the iconic Fusionopolis (http://www.a-star.edu.sg/astar/fusionopolis/index.do). We invite applications for the **A*STAR Investigatorships**, which will support and promote the independent early career development of potential leaders in scientific and engineering research. Applicants should ideally have obtained their PhD within 24 months (and at most not more than 48 months) of the application date, and have demonstrated strong ability and creativity in research.

The awards support **independent** research for a duration of 3 years, renewable for a further 3 years. The Investigatorships will be tenable at one of A*STAR's prestigious science and engineering research institutes. **A*STAR Investigators** will select a mentor from A*STAR's research institutes but will conduct and publish their research independently.

A*STAR Investigators will receive attractive remuneration, support for set-up costs, research funding, research staff and have access to state-of-the-art scientific equipment and facilities. Each **A*STAR Investigator's** laboratory would have a research allocation of up to US$500K p.a.

Candidates are invited to apply in the following areas:

- Cognitive Systems, including robotics
- Meta-materials
- Terahertz
- Clean energy technologies (including fuel cells, organic PVs, bioenergy)
- Services Science (focusing on computational approaches and computer systems to improve service efficiency and catalyse service innovation)

The **A*STAR Investigatorship Selection Panel** includes the following:

Professor Charles Zukoski, Chairman, SERC, A*STAR and Vice Chancellor for Research, University of Illinois at Urbana-Champaign

Lord Ronald Oxburgh, member of the UK House of Lords Select Committee on Science & Technology and former Chairman, Shell

Dr Bernard Meyerson, Chief Technologist, Technology Group, IBM

Professor Andrew Ortony, Department of Psychology, Education, and Computer Science, Northwestern University

Professor Richard Syms, Microsystems Technology, EEE Department, Imperial College

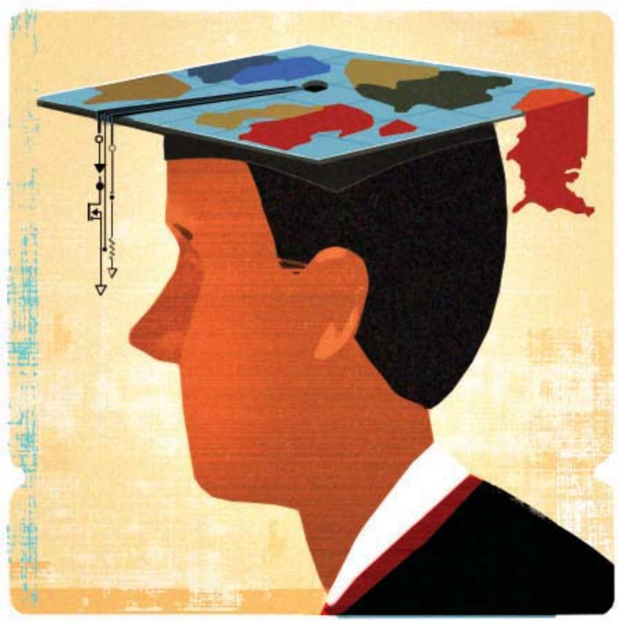
Applications will close on **31 May 2008**. Shortlisted candidates will be invited to Singapore for interviews, which will include a scientific presentation at an open symposium. These are expected to be held in **August 2008**. It is expected that the awards will commence in 2009. Applicants are requested to submit their CVs, including 3 academic referees, and a 5-page research proposal (1 hard copy & 1 soft copy) to:

A*STAR Investigatorships
Agency for Science, Technology & Research, 30 Biopolis Street, #09-01 Matrix, Singapore 138671
Email: A-STAR_SERC_Investigatorships@a-star.edu.sg
www.a-star.edu.sg/astar_investigators

Agency for Science, Technology and Research
SINGAPORE

reflections By ROBERT W. LUCKY

U.S. Engineers and the Flat Earth



YOU CAN hardly open a newspaper these days without seeing something about globalization, outsourcing, free trade, and economic competitiveness. Although the articles usually focus on policies and politics, many of the causes and consequences of globalization depend on technology and, hence, on engineers.

In 2005, a committee of the U.S. National Academies addressed this issue in a widely disseminated report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, which argued that trends in high-tech manpower threatened the United States' ability to compete in the global marketplace. While the report itself is quite voluminous, the chairman of the committee, Norman Augustine, has written a shorter version, entitled *Is America Falling off the Flat Earth?* [available as a free download at http://www.nap.edu/catalog/12021.html].

The report concludes that high-quality jobs are necessary for both individual and national prosperity and that advances in science and engineering are needed to create such jobs. A similar conclusion is reached by Thomas L. Friedman in his best-selling book, *The World Is Flat: A Brief History of the Twenty-First Century* (Farrar, Straus and Giroux, 2005), in which he says that "mathematics and science are the keys to innovation and power in today's world." The phrase "flat Earth" has become a byword for a world in which distance disappears, rendering a worker in one country interchangeable with one in any other. That means engineering work will tend to migrate to countries that bother to cultivate engineering.

If we accept these conclusions, then we must ask how to get more engineers and how to make them more productive and innovative. The first question is one I've heard discussed endlessly through the years: Why aren't there more of us engineers? I'm not sure I've ever heard a good answer to this question, and in the United States the statistics are particularly discouraging. As Augustine notes, in the past two decades the numbers of engineers, mathematicians, physical scientists, and geoscientists graduating with bachelor's degrees have declined 18 percent. As a proportion of the graduating students, the percentage decline is 40 percent. The number of engineering doctorates awarded by U.S. universities to U.S. citizens dropped by 23 percent in the past decade. Meanwhile, in the past two decades U.S. universities have increased their production of lawyers by 20 percent.

The solution to the dearth of engineers is said to lie in improving the U.S. elementary education system. Augustine, an IEEE Fellow and former CEO of Lockheed Martin, notes, "It takes a lot of third graders to produce one engineer." Yet by the time of high school graduation, only 15 percent of U.S. students have the necessary mathematical background even to consider engineering. My belief is that young students think engineering takes math (which they dislike), that it's hard, and that it's not sufficiently rewarding.

The other part of the competitiveness equation lies in our nation's innovation ecology, which has changed in the past generation. U.S. industry continues to provide funding for the incubation and implementation of ideas, but it no longer does any significant basic research, having shifted this burden almost entirely to the universities and the government. Although a number of studies have shown that society gains substantial returns for investment in research, industry has become doubtful that it can capture any of those returns for itself, at least within a period consistent with investors' expectations. As a result, industry now spends three times as much on litigation in the United States as it does on research.

In spite of the almost total dependence on government for funding engineering research, government investment in the United States has been relatively stagnant for the past two decades. The principal supporter of university research, the National Science Foundation, can fund only a small fraction of the proposals it receives.

So we engineers are largely responsible for creating the flat Earth, and we're seen as the key to mitigating its bad effects and capitalizing on its good ones. But as Augustine says, we in the United States are in danger of falling off this flat Earth. The trends are bad and look to be almost irreversible, as the pool of engineers shrinks. Elsewhere on this flat Earth, the story is quite different. ❑

MICK WIGGINS

"Where we've excelled is not only in making a very good estimation algorithm but actually making it usable" —Bill Collis, CEO of the Foundry

careers

THE FOUNDRY team [left] helped to levitate Trinity [above], a character in the *Matrix* movies.

PHOTOS: LEFT: MICHAEL YADA/A.M.P.A.S.; ABOVE: CORBIS SYGMA

OSCAR-WINNING SOFTWARE

The folks at the Foundry didn't need a pretty face to win an Academy Award

Harry Potter is a poseur. His magic powers come courtesy of the Foundry, a London-based software house whose products enhance visual effects in films. When a superhero flies past a backdrop, this firm's software probably trimmed away the wires holding him up.

The development work is done in a nondescript third-floor office in the center of the city. There, 37 staffers huddle cheek by jowl facing banks of computer monitors, an adjacent storage room with its two faded red couches offering the group their only respite from the flickering screens. The company has been just too busy to spruce things up. In the past year it opened a Los Angeles sales office, doubled its staff, and ramped up product development.

Hollywood took notice last year, awarding the firm a technical Oscar, the Academy of Motion Picture Arts and Sciences Scientific and Technical Award (for this year's winners, see the 17 January entry in our blog at http://blogs.spectrum.ieee.org/tech_talk). Still, any Tinseltown glamour is checked at the door.

"Getting an Academy Award was recognition for how well we were doing, so it has to have had an impact on the marketability of the company," says chief scientist Simon Robinson. "It's really hard to know exactly what, since we've really just had our heads down before then, during then, and ever since then."

The Foundry team won its award for a program called Furnace, a six-year-old package that has seen service in such image-editing-nightmare assignments as the *Lord of the Rings* trilogy, the *Harry Potter* franchise, and the various *Matrix* films.

Furnace tracks the motion of objects from one frame to the next during postproduction, saving time, freeing artists from monotonous manual work, and helping them to maintain better continuity. The software license sells for about US $5000, but the product can pay for itself in a matter of weeks by cutting up to 40 percent of the labor needed in postproduction.

Other motion-estimation packages exist, but they're generally not as flexible, says the Foundry's CEO, Bill Collis. "Where we've excelled is not only in making a very good estimation algorithm but actually making it usable," he says. Collis accepted the award with Robinson, senior software engineer Ben Kent, and consultant Anil Kokaram, a lecturer in electrical engineering at Trinity College, Dublin.

Furnace subserves several dozen functions. One tracks particular patterns of pixels as they move over a background—say, wires suspending a superhero—so that editors can change their color or wipe them away.

Another function, called global motion estimation, tracks an entire background. If you want to excise a blurry item, the program will find you the right bit of background to cut and paste over the object. Still another function, called retiming, enables filmmakers to extend an image sequence by inserting artificial frames between real ones.

Robinson, a computer scientist, and Bruno Nicoletti, a software engineer, formed the Foundry in 1996 to tackle special-effects plug-ins. Their goal was compositing—the digital combination of many images into one. They began developing Furnace after joining forces with Collis, an electrical engineer who suggested ways to combine motion-estimation and image-processing algorithms. Kent, an electrical and information sciences engineer, arrived in 2000 to help translate those ideas into a commercial product.

Half of the employees are developing new products or new versions of older ones. Some are rewriting Keylight, a program acquired from London-based Framestore CFC, so that it can work with new applications while performing its main job of manipulating elements from footage shot on green or blue screens. The firm also has a deal to enhance and market Nuke, a digital-compositing program from Digital Domain, in Venice, Calif.

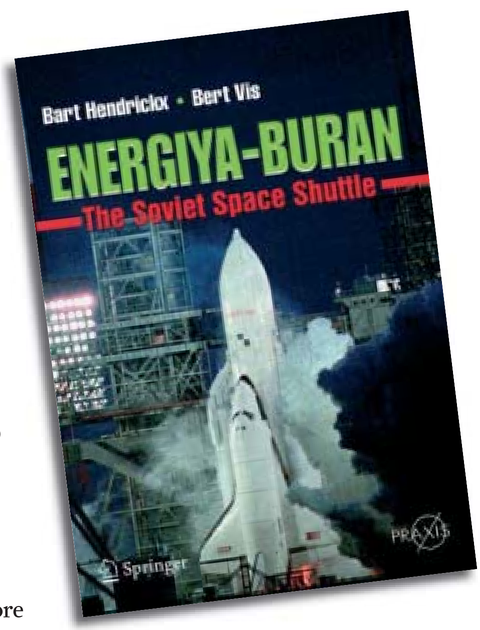
"For a company of our size, we devote a huge amount of manpower and money to research," says Robinson. "Luckily, customers don't come here, so they don't know that we're living in a shoebox. When we do move, the decor will improve."

—Susan Karlin

books

COPYING NASA'S MISTAKES

The Soviet version of the U.S. space shuttle was an engineering marvel but a total waste



ENERGIYA-BURAN: THE SOVIET SPACE SHUTTLE
By Bart Hendrickx & Bert Vis;
Springer-Praxis, 2007; 526 pp; US $69.95
ISBN: 978-0-387-69848-9

In 1988, the Soviet Union achieved its first and only space shuttle flight, with the *Buran* ("blizzard" in English) space plane. It flew two orbits of the Earth on autopilot and landed safely on a runway at its launch site, the Baikonur Cosmodrome, an impressive feat. However, its cost helped to bankrupt the Soviet space program just before the Soviet Union itself collapsed. Later, the roof of the spaceship's hangar fell in, crushing it into scrap metal.

Now a pair of amateur European space historians have published the first full account of the project, just in time for analysts in both the United States and Russia to learn from the affair as they look to develop new spacecraft for human flight. There is a lot for them to learn: many misjudgments led the Soviet Union to needlessly duplicate NASA's shuttle program, which had itself been poorly thought out.

The authors did their work extremely well, relying on archives and interviews, mostly in Russian, and they have provided a balanced, technologically insightful, and well-illustrated narrative. All dimensions of the project—the vehicle, its support infrastructure, the training of the crew, and the planning of the mission—are an integrated whole. Of particular interest to *IEEE Spectrum* readers are details never before made available about the spaceship's power, guidance, and communications systems.

The *Buran* was to carry four fuel cells (code-named Foton), compared with NASA's three. Like the U.S. shuttle, *Buran* could also carry extension kits for enough cryogenics to support longer missions. But *Buran* had one big difference: it also carried chemical batteries for 24 hours of emergency power, in case the fuel cells failed. Because the first flight lasted only 3 hours, the fuel cells were not installed, and so they never got a chance to fly in space. *Buran* was controlled by four Biser-4 computers running parallel software. The 130 kilobytes of RAM had to be reloaded from tape units as new flight phases occurred. The flight software's development problems appear to have closely paralleled the U.S. experience.

Buran's radio links operated through line-of-sight VHF and UHF bands as well as centimeter waveband, or SHG (super high frequency), which is managed by a set of geosynchronous relay satellites. Launched in the 1980s, the satellites were also used by the *Mir* space station. Following the collapse of the USSR in 1991, none were replaced, and the on-orbit payloads all ceased operating within a few years.

The authors provide an excellent transition to the post-*Buran* period, as Russian space engineers tried, with little success, to salvage some of the work done for this project. Symbolic of this is the fate of one of the *Buran* test vehicles, which ended up as a riverside restaurant in a Moscow park.

The program's engineering was probably the best in the history of the Soviet space program, but because the political and social underpinnings were rotten, the engineering work was tragically wasted.

—James Oberg

tools&toys

Robotic Photographers

The GigaPan takes the tedium out of shooting panoramas

YOU DON'T want to look at the Grand Canyon through a keyhole—you want it in all its glory, in a panoramic view. That means taking a lot of overlapping photos and stitching them together, one by one.

Now there's a robot that can do the job for you. Called the GigaPan, it's a small gray box with a black frame that holds your digital camera in place on top of a tripod. Once programmed, it automatically captures hundreds of photos that software later splices into a high-resolution, gigapixel image.

Chalk it up as one of the space program's few genuine spin-offs, the product of NASA's work on visualization and image analysis for Mars missions. The commercial developer is the Global Connection Project, led by Carnegie Mellon University and the NASA Ames Intelligent Robotics Group, with financial support from Google. This past fall, a beta version was distributed to about 400 people around the world. The manufacturer, Charmed Labs, in Austin, Texas, expects to sell the retail version for US $350.

Programming is easy. Four buttons allow you to pan and tilt the camera. You set the boundaries of the panorama by making the GigaPan point first to the top left and then to the bottom right corners of the chosen scene. A two-line LCD screen leads the user through the process. The device then calculates how many pictures are needed and asks the user to make sure the camera has enough memory to store them. After checking a few more camera settings, the GigaPan moves over to the left and begins snapping away, using a lever to push the camera's button.

The robot takes the photos in an orderly grid, column by column. A really big panorama—say, a 360-degree view of Paris photographed from the top of the Eiffel Tower—can take more than an hour to shoot.

Later, your computer runs custom software developed for the GigaPan to piece the images together. The software knows precisely where the camera was pointing for each picture, enabling it to line up the images almost seamlessly—a big advantage over shooting panoramas manually. The stitching process requires about half a minute per picture, so a panorama with a hundred images would take less than an hour to assemble. One with a thousand pictures could take all night.

You can share the resulting panoramas on the GigaPan Web site (http://gigapan.org). Visitors to the site can maneuver around inside a panorama, zoom in for a closer look, and capture still frames to highlight interesting parts of the shot. Google Earth 4.2 also has a layer that features selected panoramas.

The camera is the only limiting factor. The more it can zoom in on a target, the more detail it can capture in each shot. The current GigaPan can't hold heavier single-lens reflex cameras, only the consumer-level, point-and-shoot cameras that most people have.

Of course, the world won't stay put while the GigaPan snaps away—the lighting may change, people may move, and some objects may get cut off. But in a way, those quirks can make the panorama more interesting, almost like a time-lapse exposure.

The GigaPan is a cool toy with a grander purpose: to give people the means to document the world around them and put it online for anyone to explore.

—CORINNA WU

THE GOLDEN TEMPLE, Gujarat, India, is stitched from dozens of snaps, totaling 657 megabytes—enough detail to zoom in on a face in the crowd. The shoot was managed by the GigaPan [below]; the even more laborious quilting job, by the associated software.

PHOTOS: TOP: MATT DEANS; BOTTOM: SCOTT TELSTAD/GLOBAL CONNECTION PROJECT

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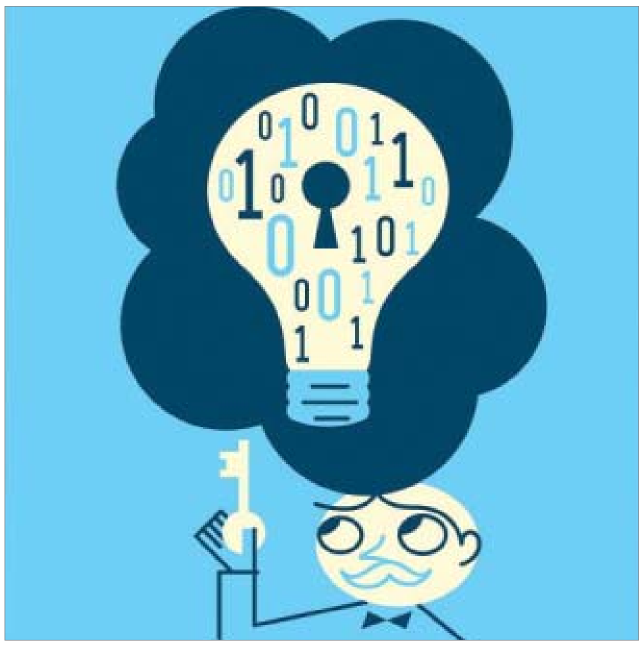
The trade secret is encumbered with a lot of conventional wisdom that happens to be dead wrong

invention

SOFTWARE PATENTS 101

To protect your intellectual property, choose the best tool for each stage in its creation



THE FOUR pillars of intellectual property—patents, copyright, trademarks, and trade secrets—all play roles in protecting software. No wonder this is one of the most slippery subjects for an engineer's lawyer.

Luckily, the courts have established a framework that matches the way the real world works (up to a point). The framework begins by considering three milestones in software development: function, design, and code.

At the highest level of abstraction stand the *functions* that software performs. These functions are often specified formally. For the first word-processing program to include a cut-and-paste function, the spec might have read: "The program shall allow a user to highlight a section of text and move or copy that section of text elsewhere."

Design refers to the plan by which the software will carry out the functions—which in patent applications often appears as a flow chart showing how the various subroutines, modules, and algorithms interact.

Finally, there is the *code*—the instructions that carry out the functions according to the design.

It is in moving among these three levels that the disparity between patents and copyright becomes clearest. By law, copyright can never protect functionality. And, there is a great uncertainty concerning even how much of the software design copyright can reach. Older court cases touting ideas like the "look and feel" of a software interface and the protection of "selection and arrangement" constituted attempts to protect software design. Those cases have now mostly been discredited. Even the notion of copyright protection for the code is limited, because it doesn't apply to code taken from the public domain or mandated by hardware or software constraints.

The good news about a copyright, though, is that it's relatively simple and inexpensive to register one. The code doesn't have to be inventive, new, or unobvious; technically, it doesn't even have to work. So in spite of the limits, you are well advised to register a copyright for all important software code.

Patents, in sharp contrast, are designed to protect functionality, usually not by covering specific lines of code but rather by covering a software "engine" that takes certain inputs, manipulates them, and provides certain outputs. The bad news is that patents are expensive, and you have to prove that the functionality you want to protect is new and unobvious.

Patents can also protect software design. An example: suppose someone else has already invented the cut-and-paste function, but you have designed a faster or more intuitively comprehensible way to perform the function. The "and improvements thereof" allowance in patent land would protect your refinement.

Next on the list of IP weapons is the trade secret, which is encumbered with a lot of conventional wisdom that happens to be dead wrong. Trade secrets do not offer free protection, they do not provide a fallback position, and they include several severe restrictions. They cannot protect function if it is publicly known—that cut-and-paste function, for instance, is not only *not* a trade secret, it's an advertised feature. Trade secrets can, however, protect design or code, provided that you take active (and sometimes expensive) steps to invoke a company-wide program that will hold up in court.

The final weapon is trademark, which has little to do with function, design, or code but protects only the commercial name of the program. "Windows" is a trademark; so are the names of the software products advertised in this magazine. Trademark registrations are only moderately expensive and can be obtained fairly easily.

The function, design, and code demarcation should be kept in mind as we continue to debate any meaningful IP reform. Meanwhile, for any important software product, the general consensus is that all species of intellectual property should be explored and their various levels of protection exploited.

—KIRK TESKA

GREG MABLY

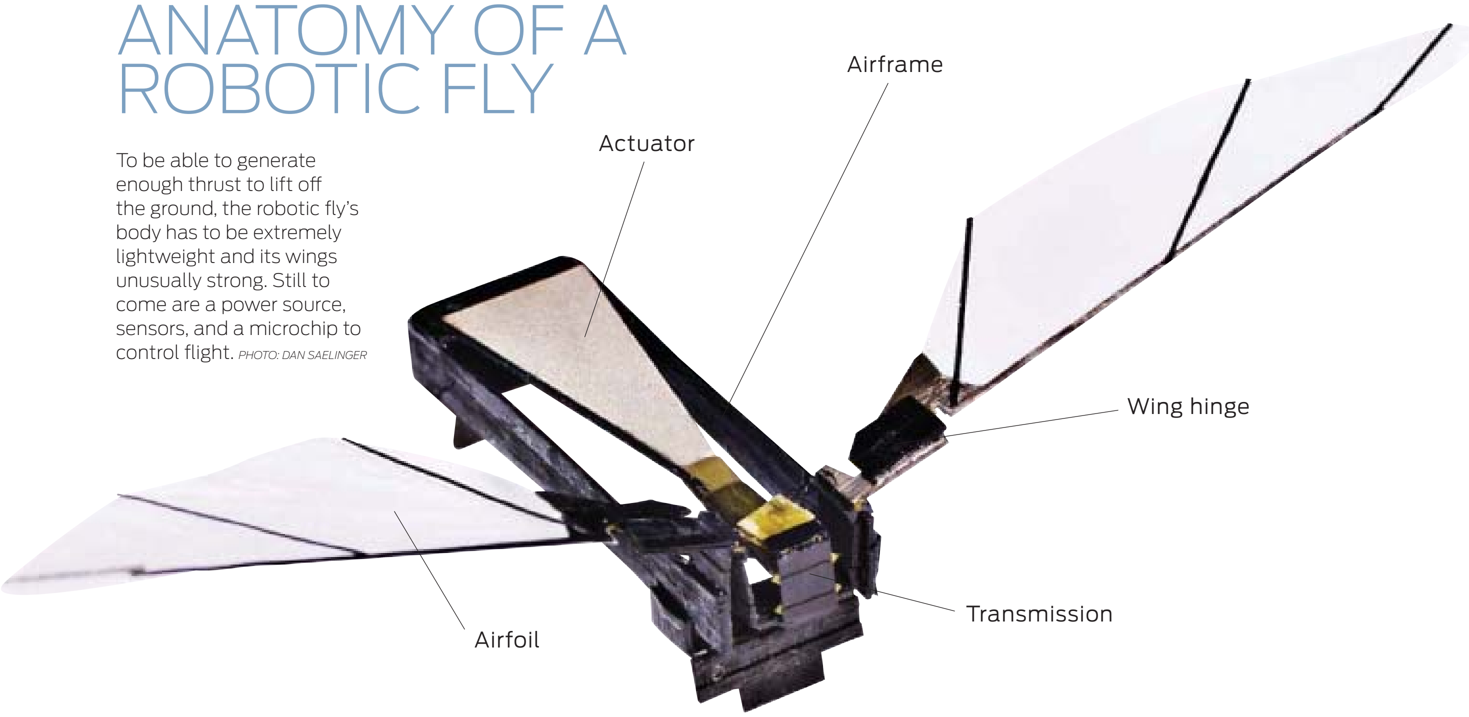
FLY, ROBOT FLY

Whether as rescue robot or flying spy, this micro-aerial vehicle could change how we look at the common housefly

By Robert Wood

ANATOMY OF A ROBOTIC FLY

To be able to generate enough thrust to lift off the ground, the robotic fly's body has to be extremely lightweight and its wings unusually strong. Still to come are a power source, sensors, and a microchip to control flight. PHOTO: DAN SAELINGER



THERE IS NO more rewarding moment for roboticists than when they first see their creations begin to twitch with a glimmer of life. For me, that moment of paternal pride came a year ago this month, when my artificial fly first flexed its wings and flew.

It began when I took a stick-thin winged robot, not much larger than a fingertip, and anchored it between two taut wires, rather like a miniature space shuttle tethered to a launchpad. Next I switched on the external power supply. Within milliseconds the carbon-fiber wings, 15 millimeters long, began to whip forward and back 120 times per second, flapping and twisting just like an actual insect's wings. The fly shot straight upward on the track laid out by the wires [see photo, "Winged Victory"]. As far as I know, this was the first flight of an insect-size robot.

The experiment was the culmination of nearly a decade of work that began in the laboratory of my then-advisor, Ronald S. Fearing, a professor of electrical engineering at the University of California, Berkeley, and later migrated to my lab at Harvard. The little flying robot, we hope, will herald a new era of practical small-scale robot design.

The insectlike robots that my colleagues and I at the Harvard Microrobotics Laboratory are creating are intended to perform rescue and reconnaissance operations with equal ease. Once they can be fitted with onboard sensors, flight controls, and batteries, they will be freed from their tethers to the lab bench to nimbly flit around obstacles and into places beyond human reach.

For example, when a severe earthquake breaks the crust of the Earth and collapses buildings, rescue workers must frantically search for survivors while breathing air full of toxic particles and making their way through rubble-strewn passageways. They must do so on their own because our most sophisticated rescue robots falter and often fail when they encounter even mild clutter.

We envision a very different approach, in which emergency personnel disperse thousands of paper clip–size flying robots throughout a disaster zone. The tiny machines would detect signs of life, perhaps by sniffing the carbon dioxide of survivors' breath or detecting the warmth of their bodies. Though some flies might smash into windows or get stuck in corners, others would slip through cracks and under fallen crossbeams. Perhaps only three members of the swarm make their way to the survivors, where they perch and expend their remaining energy broadcasting their findings to rescue workers. They may have onboard radio-frequency transmitters to communicate short, low-bandwidth chirps, to be picked up by receivers installed around the perimeter of the site. Even if 99 percent of the robots are lost, the search mission would still be a success.

Designing a robotic insect is more complicated than simply shrinking a model airplane, however, because the aerodynamics that govern flight are entirely different on the scale of insects. The basics of insect-flight aerodynamics in different patterns of airflow first became clear in 1999, when Michael Dickinson, a biologist then at Berkeley and now at Caltech, built a 25-centimeter replica of a fly's wing and simulated the viscosity of air on a small scale by submerging the wing in a vat of mineral oil. It turns out that insects use three different wing motions to create and control the air vortices needed to generate lift.

Using the results from Dickinson's models, I and others in Fearing's lab set out to replicate the insect's incredible wing motions. Part of the chal-

PREVIOUS PAGE: DAN SAELINGER

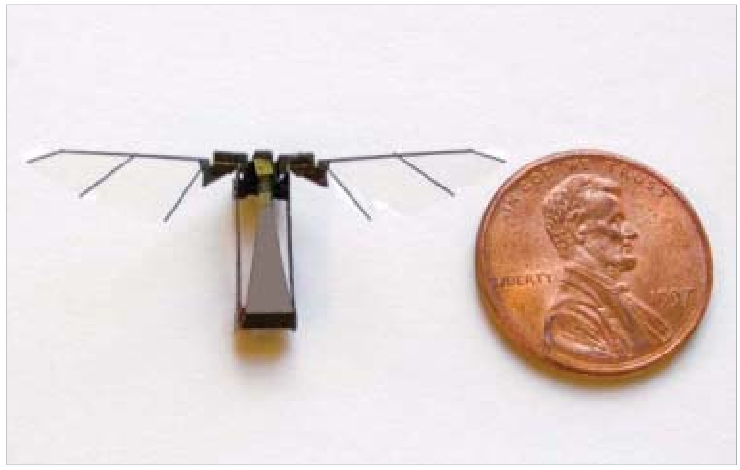
lenge is that many systems contribute to the flight of a fly, including eyes specially attuned to perceiving motion and powerful muscles that drive the wings to generate unsteady aerodynamic forces, on which the fly's maneuverability depends. Most insects control their wings by adjusting the amplitude of their wing strokes, the angle of attack, and the tilt of their strokes through tiny muscles in the thorax. Flies even have special sensory organs, called halteres, that sense body rotations during flight. These features are all key to flies' remarkable ability to hover, fly upside down, and land on walls and ceilings.

THE MAIN MOTIVATION for creating mobile robots is that they can go where humans cannot—to exposed points on a battlefield, for instance. Today, mainly the military can use such robots, because they cost on the order of US $100 000 each. To bring robots within the reach of law-enforcement and emergency-rescue services requires a totally new approach. We placed a great deal of importance on our choice of materials, which ultimately had to be cheap and fairly easy to work with. Durability was less important, because we envisioned a robot that could be replaced for less than $10.

We focused on the two-winged insects of the order Diptera, which includes houseflies, hoverflies, and fruit flies. Flies are the most able flyers on the planet, they're small, and they are naturally robust enough to survive collisions.

Flies achieve their astonishing maneuverability by moving their wings through complex, three-dimensional trajectories at frequencies that often exceed 100 hertz. The upstroke and downstroke patterns are almost symmetrical when flies hover but highly asymmetrical when they move forward or maneuver. Flies generate those large-amplitude, high-frequency wing strokes by using indirect flight muscles, so called because they deform a portion of the thorax rather than the wings themselves, inducing mechanical resonance in the fly's body. Smaller muscles connect directly to the wing hinge to fine-tune the wing's movements.

Because of the small scale, the airflow around a fly is much more viscous than that around birds or fixed-wing aircraft. For insects, flight is somewhat like treading water. A fly's wing motions generate aerodynamic forces that can change magnitude drastically in a fraction of a second. Traditional aircraft wings, by contrast, are subject to fairly steady fluid flow. Because of this difference, the analytical tools that are used to predict the performance of an airplane are of little use in predicting the flight dynamics of an insect, making our job more difficult.



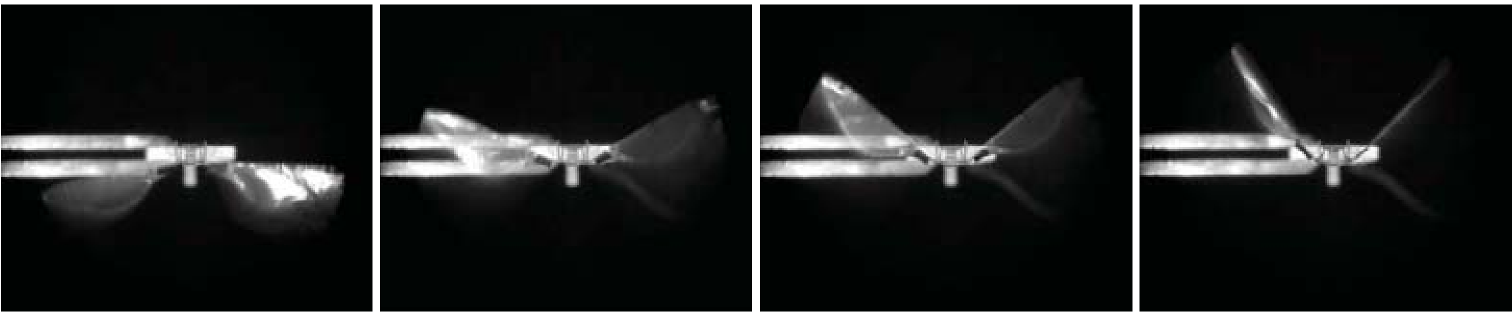
TINY FLY: Each prototype has a wingspan of 3 centimeters and weighs 60 milligrams, not including a battery and sensors. For now, the fly is connected to an external power source.
PHOTO: RANDI SILBERMAN

Over hundreds of iterations, our robotic fly has followed its own evolutionary path to more and more closely resemble the shape of a real fly. We borrowed two basic principles from biology—the ratio of the wing area to the body mass and the wingbeat frequency. Still, we need not copy nature slavishly by putting up with limitations on invertebrate biology that electromechanical devices do not share. Take, for instance, the elastic and structural properties of the insect thorax and wings. These body parts are made of chitin, a common polysaccharide, which though tough is nonetheless substantially weaker than carbon fiber.

Our fly has all the same primary mechanical flight components of an actual fly: an airframe (exoskeleton), actuators (flight muscles), a transmission (thorax), and airfoils (wings) [see diagram, "Anatomy of a Robotic Fly"]. The function of each is simple. The airframe must provide a solid mechanical ground for the actuators and transmission. The actuators power the thorax at mechanical resonance. The transmission maps actuator movements to the desired wing motions. Finally, the airfoils must remain sufficiently rigid to maintain their shape in a number of radically different aerodynamic conditions.

Our design takes due note of the physics of the

WINGED VICTORY: The robot's maiden flight last March was a landmark in microrobotic research. As shown below, guide rails constrain the robot to fly only upward for now.
PHOTO: ROBERT WOOD



TWIST AND FLAP: To insects, flying is a lot like treading water. Flies have evolved complex mechanisms to regulate their flight, including performing intricate flapping and twisting wing movements, which the robotic fly does 120 times a second. A clamp holds the robot in place to keep it from escaping the camera's lens. PHOTOS: ROBERT WOOD

minuscule. As the parts of a robotic device shrink, surface forces begin to dominate the dynamics of motion. Bearings become less efficient because a decrease in size means an increase in the surface-area-to-volume ratio and thus in friction. However, just because we designed the robot didn't mean we knew how to make it, and mechanical components with features of one micrometer are well below the resolution of standard manufacturing techniques. Nor could we turn to processes employing microelectromechanical systems, or MEMS, which use materials that are too fragile for the forces a robotic fly must withstand. What is more, it takes a lot of time to turn out a prototype with MEMS, and our design strategy entails building a lot of prototypes.

OVER HUNDREDS OF ITERATIONS, OUR ROBOTIC FLY HAS FOLLOWED ITS OWN EVOLUTIONARY PATH TO MORE CLOSELY RESEMBLE THE SHAPE OF A REAL FLY

My approach has been to develop a process based instead on laser micromachining and thin materials, usually carbon-fiber-reinforced composites, laminated to have precisely tailored stiffness and compliance. Using these fairly simple techniques, we can make a fly prototype in less than a week.

To build a joint, we make gaps in two thin, rigid sheets of carbon fiber. We sandwich between them a thin-film polymer, which can bend repeatedly without losing its ability to flex. Four such joints, connected in series by flat, rigid carbon-fiber links of various lengths, make a microscale transmission. With a proper choice of link lengths, the transmission can amplify the small angular motions of one link into larger movements of the opposite link.

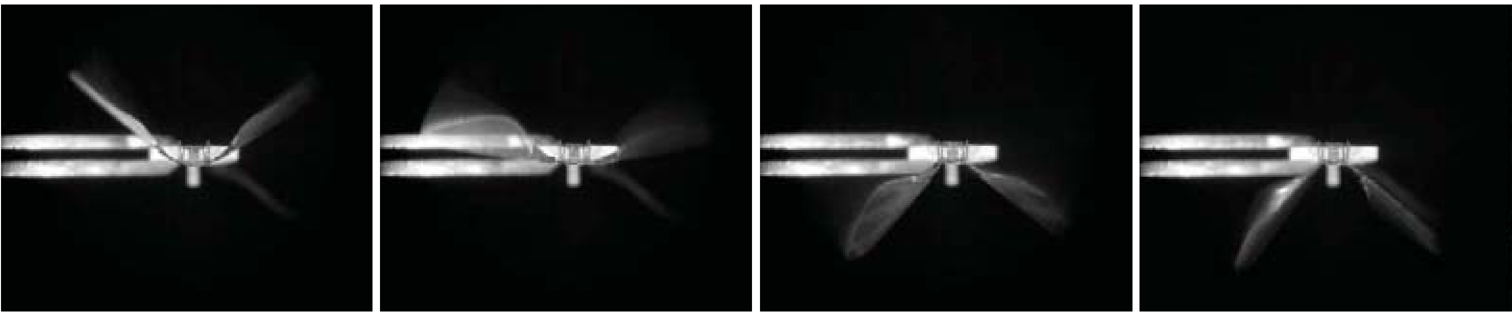
To make actuators that mimic real flight muscles, we add to the carbon-fiber-based composite a few layers of an electroactive material, which changes its shape when an electric field is applied. Designing these actuators to be as small and light as possible, while keeping them strong enough to deliver sufficient power, was our first key accomplishment. The power density of our robot's actuators comes to more than 400 watts per kilogram, some four times that of an ordinary fly's wing muscles. Our second breakthrough came when we successfully converted the actuator movements to biomimetic wing motions, using a four-bar linkage. Only after we made the transmission did we discover, to our great satisfaction, that its mechanism is remarkably similar to a dipteran fly's thorax driving its wing movements.

Our latest version weighs 60 milligrams, about the same as certain dipteran flies, and can generate nearly twice its weight in thrust. That's almost on par with a real fly, which typically can attain lift forces three to five times its weight. Our immediate goal is to get the fly to hover, which is key for maneuvering in constricted environments. A hovering vehicle can turn itself in place and does not require forward motion to remain aloft.

To achieve stable, untethered flight, we will need to miniaturize and install three more things: sensors, controls, and a power source. A number of laboratories and companies are developing a promising suite of sensors, inspired by biological sensory systems, to enable the robot to stabilize its own flight and to control simple behaviors. My former advisor Ron Fearing's work at the Biomimetic Millisystems Lab, at Berkeley, has demonstrated bio-inspired gyroscopes and sensors capable of detecting the horizon. Centeye, in Washington, D.C., has built vision sensors weighing less than a gram to help flying robots navigate.

Control remains a challenge. A real fly can make rapid turns, called saccades, because it has a specialized neural system that allows for speedy responses. In a fly, neural impulses from internal feedback sensors directly modulate the flight muscles—without processing from the central nervous system—to counter disturbances. We are studying practical ways to emulate this system by using inputs from a number of attitude sensors that figure out the orientation of the fly and directly manipulate the actuators.

Then there's the question of getting a power source onto the fly. A battery small enough to fit aboard



a robotic fly will have a much higher surface-area-to-volume ratio than its macroscale counterpart, so a greater percentage of its mass will be the packaging. We expect that scaled-down versions of today's best lithium-polymer batteries will weigh about 50 mg, accounting for half the fly's weight, and will provide 5 to 10 minutes of flight. For more flight time we will have to increase the battery's energy density, make the propulsion more efficient, or develop energy-harvesting techniques, perhaps by mounting tiny solar panels on the insect's back or converting the fly's vibrations into electric current.

We're now turning our attention to the robot's low-power, decentralized control algorithms. Again, we begin with nature. Social insects use simple local rules and minimal direct communication, yet they achieve tasks of astounding complexity. For example, termites can produce a structure millions of times their own size, even though no one termite has a blueprint for it. We believe that our robots can eventually be used as tools to study such insect behaviors; what we learn could then help us to design algorithms to enable swarms of simple robots to accomplish complex tasks.

Even with basic control algorithms, however, we expect microrobots to be able to perform useful roles as ad hoc mobile sensor networks. Search-and-rescue operations, hazardous environment exploration and monitoring, planetary exploration, and building inspections are just a few of the potential applications for highly agile, insect-scale rescue robots. Smart sensors on wings are not a distant dream: we predict that a fully autonomous robotic insect will be flying in laboratory conditions within five years. Five years beyond that, we could begin seeing these devices in our daily lives. ❑

TO PROBE FURTHER For a video of Robert Wood's microrobotic fly and more on robotic-insect research, see http://www.spectrum.ieee.org/mar08/morefly.

NEXT-GEN UFOS?

Insectlike robots have reached new milestones on the path to full autonomy, and the public has become more aware of them, as well. This past October, protestors in Washington, D.C., claimed they saw strange-looking, larger-than-life dragonflies hovering above the crowd. Were they actually flying robots? Probably not. But the mystery of their sightings hasn't been resolved, and it has spooked the public enough to raise concerns about new frontiers in domestic spying. Indeed, a robotic insect would make the perfect spy, but there are other, benevolent uses. Swarms of small, agile robots could be great for all kinds of exploration, such as investigating other planets, penetrating hazardous environments, and monitoring traffic. What's more, they would make great toys! —*R.W.*

CLOCKWISE FROM TOP RIGHT: CARLYE D. LA POINTE/U.S. AIR FORCE; TIM MCCAIG; NASA

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the lady and the li-ion

Laptops desperately need a better lithium-ion battery. Boston-Power's Christina Lampe-Onnerud says she's got it

By Tekla S. Perry   Photos by Chris Mueller

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THESE DAYS, Lampe-Onnerud is working 80-hour weeks, meeting with potential customers and investors, overseeing the manufacturing ramp-up in China, and working with members of the company's executive team around the world. On a typical day, she's up at 5 a.m. to check in with Boston-Power's team in China; at 7 a.m. she reads her e-mail, and then from 7:15 to 8:30 she's feeding the kids breakfast and getting them ready for school. From 9 a.m. to midafternoon it's meeting after meeting. She and Rick Chamberlain, Boston-Power's vice president of engineering, discuss a new customer at 10 a.m. [above, left].

YOUR WORLD increasingly runs on lithium-ion batteries. Chances are good that your phone, laptop, camera, portable music and video players, radios, and game consoles keep going only as long as there are lithium ions churning around inside them. Lithium-ion batteries are getting into your power tools. Soon they'll even be in your car.

So it's a shame that after nearly four decades of intensive development, lithium-ion batteries still leave plenty to be desired. They fade fast—although their energy capacity starts out higher than that of any other kind of mass-market battery, it can drop more than 25 percent per year in typical applications. And then there are the persistent reports of flameouts: just this January, journalists gathered at a Korean hospital witnessed a colleague's laptop burst into flames. Remember the iPod that burned up in a man's back pocket, or the Dell laptop that went up in flames at a conference in Japan? Their former owners sure do.

This is an industry ready for change but not necessarily expecting it, let alone striving for it. The big companies that dominate lithium-ion production—Sony, Panasonic, Sanyo, Samsung, and LG—are all selling batteries not much different from the ones they sold five years ago. Only the initial capacity of batteries has been increasing, at about 5 percent a year. Today they are commodity products, manufactured in huge quantities and sold at vanishingly slim profit margins.

Change, however, is about to come. And it's going to come from a pretty surprising agent: a 40-year-old jazz singer, soccer mom, and research chemist named Christina Lampe-Onnerud.

Since 2005, Lampe-Onnerud has quietly redesigned the lithium-ion battery used in today's laptop computers. She started a company called Boston-Power, in Westborough, Mass., to build the novel batteries, collected nearly US $70 million in investment, set up manufacturing lines in China and Taiwan that have so far cranked out tens of thousands of units, and expects to see her batteries in products shipping from major laptop manufacturers later this year. And as if that's not enough, she's managed to get her batteries certified to carry the Swan label, indicating they are environmentally friendly under the Nordic ecolabel program, the first lithium-ion batteries ever to receive such a designation.

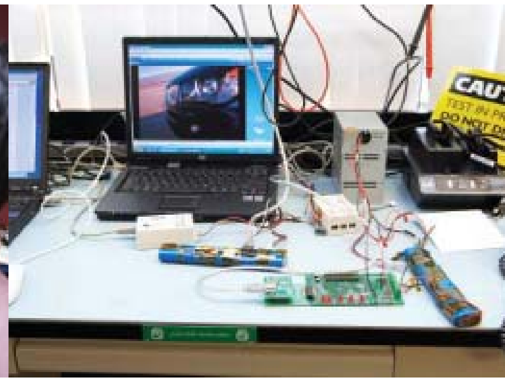
LAMPE-ONNERUD had her career-altering moment in 1999, at the 40th Battery Symposium, in Kyoto. She ruffled a few feathers there by pointing out in a talk that the energy density of lithium-ion batteries used for laptop computers, at 40 watt-hours per kilogram, was already getting uncomfortably close to that of your basic hand grenade. That density, the amount of energy stored in a certain mass, had been going up like a rocket as manufacturers competed fiercely for a growing market.

At the time she was a partner at consulting firm Arthur D. Little, in Cambridge, Mass., advising battery companies, doing market forecasts, and troubleshooting technical and manufacturing problems. She gave lots of speeches at conferences, most of them saying the same thing: as lithium-ion makers squeezed more and more energy out of their batteries, they were also going to get squeezed on cost. Put those two trends together, she told battery makers, and bad things might happen. None of the manufacturers became overly alarmed.

Then, in 2002 and 2003, battery manufacturers indeed started having problems with unpredictable failures—none of which, at this stage, involved flaming consumer goods. Manufacturers addressed the failures, "but the solutions were always just patches," she says. By 2004, Lampe-Onnerud was tired of helping the industry slap on Band-Aids: "I wanted to take a step back and think about the whole battery as one system." And she couldn't do that within Arthur D. Little.

So on Halloween 2004, she cleaned out her office at Arthur D. Little, said good-bye to her colleagues, and went trick-or-treating with her kids. The next day Lampe-Onnerud dropped her children off at preschool and then walked up the stairs to her study, where she opened her laptop, took a deep breath, and began to think about lithium-ion batteries in a way no one else ever had before.

Lots of people find their life's calling only after circuitous adolescent self-discovery. But not many engineers find their way



after rejecting opera singing and medicine. Christina Lampe grew up enchanted with opera in her native Sweden. But her father, Wolfgang Lampe, a power engineer who was named an IEEE Fellow for his innovations in high-power transmission, encouraged her to make performing arts a sideline and pursue a more traditional career in math or science.

She did find science fun as a child, playing with electronics and chemistry kits. By the time she was 12, she was concocting fireworks in a basement bathtub, slapping out stray sparks with damp towels. In high school she applied to and was accepted by a prestigious eight-year program in Sweden that would end with a medical doctorate. But during her senior year of high school, in 1985, with memories of a recent fun-filled summer in Oregon fresh in her mind, she instead accepted a scholarship from a Swedish-American association to go to college in the United States. She spent a year at Elmira College in New York, taking double the normal course load and studying English literature, business, and various sciences and working for one of the chemistry professors as a lab assistant. In the spring, the students voted Lampe "Miss Elmira."

She went back to Sweden to finish her education at Uppsala University, but by this time she'd turned away from medicine for good. An Elmira chemistry professor, Pierre-Ives Bouthyette, had convinced her that chemistry was far more interesting than anatomy. Anatomy was simply memorization, while chemistry was literally the stuff of the world. With chemistry, "you had to see beyond what the science was," she says, and understand what the science could make happen.

It came easily enough to her. Lampe began graduate studies at Uppsala, focusing on copper deposition on semiconductor wafers for her master's work and analyzing cathode materials for lithium-polymer batteries for her Ph.D. While completing her degree, she collaborated with a battery company called Danionics, in Odense, Denmark. Danionics patented the synthesis of some of the vanadium-oxide cathode materials she worked on for her Ph.D.

On the day Lampe was due to defend her Ph.D. thesis, she publicized the event; she was giving a live interview to a radio journalist as she entered the room. "The thing that separates Christina from others is her ambition," says Josh Thomas, the professor who supervised her Ph.D. work.

She could hardly have timed her thesis better. When she got her Ph.D. in 1995, commercial lithium-ion batteries were still fairly novel. Lampe quickly became known as a lithium-ion cathode expert. Not that she fixated completely on batteries: she also worked for the town of Uppsala, leading its 120-singer chorus, and married her high school sweetheart, Per Onnerud, who was studying chemistry and math and playing jazz trumpet in a local band.

After graduation, the two went to MIT as postdoctoral researchers. Lampe-Onnerud worked part-time for an MIT spin-off, Quantum Energy Technologies, where she concentrated on batteries and displays, before moving in 1997 to Bell Communications Research (Bellcore), in Red Bank, N.J., as director of energy storage. The Bellcore gig was fun but short-lived. Executives at Arthur D. Little, the management-consulting firm, had begun wooing Lampe-Onnerud the day she left Massachusetts for Bellcore. They called at least once a month. They sent gift baskets. And finally they offered to hire her with her husband and assign them to work together, something Bellcore wouldn't do.

She left New Jersey in 1998 to become a partner at Arthur D. Little and stayed for six years, working with companies, industry groups, and governments to help them understand the battery market, defend battery patents, and set energy policy. She continued her cathode research, now to advance technology for Arthur D. Little clients; companies credited her on several patents.

And then, as summer turned to autumn in 2004, she realized she was weary of having to think about batteries in the ways her clients wanted her to. She had two children, aged 1 and 4, but she also had child care. The family could live on her husband's income. She even had an unrenovated carriage house on her Framingham, Mass., property, which could be company headquarters. For a while.

For those last two months of 2004, Lampe-Onnerud spent most

AROUND NOON, Lampe-Onnerud meets with senior scientist Yanning Song to discuss test results [opposite page, center], and then at 1:45 with members of the company's electronics group [opposite page, right]. At 2:15 she gets an update on the production scale-up from Phil Partin, associate director of product development [above, left], then checks out testing in progress [above, center]. On most days she then rushes home to greet her children returning from school. From 3 to 7:30 it's family time, which involves music [above, right] and play with children Anna-Maria and Mattias [next page, left].

PER ONNERUD, Lampe-Onnerud's husband, often puts the children to bed while she works in her home office; here [above, center] she meets with him to prepare for late-night conference calls with factories in China and Taiwan. At 11 p.m. she's back in her home office [above, right]; this is when she can wrestle with scientific questions or think strategically about her company. She gets to bed around 1 a.m. most nights. Thursday evenings, however, are different. Lampe-Onnerud sings with and directs the Stardust Show Chorus, a 20-member women's jazz chorus. Thursday is rehearsal night.

of her time in her study, figuring out what her newborn company should do. "You get an innovation euphoria going," she says, and "you barely need sleep." Her husband dealt with the children as much as possible. Friends and neighbors dropped off meals for the family. She drafted spreadsheets, one sorting out technical issues in the battery industry, another looking at financial opportunities.

She considered developing a battery for active RFID. She considered implantable batteries for medical devices. She even thought about batteries for hybrid cars, but she kept coming back to the laptop market as the most interesting niche. She reviewed cases in which laptop batteries had problems, and she found something interesting: what all those incidents had in common was that people were jamming too much energy into a confined space. A laptop's battery slot determines the boundaries of that space but not the divisions within it. So Lampe-Onnerud reorganized the space within. And just as a simple kitchen remodel can make a family's life more efficient, the reorganization made all the difference. The solution, she says, looks simple now. At the time it was anything but.

TRADITIONAL LAPTOP batteries consist of six cylindrical cells, arranged as pairs wired in parallel, with three sets of parallel cells wired in series. Lampe-Onnerud sketched out a design with three rectangular cells instead, each filling the space of two cylindrical cells, all wired in a series. Could such a simple change make a difference? It could. In the parallel laptop battery, current is supposed to flow through the parallel paths at exactly the same rate. But slight temperature differences or tiny chemical imbalances between the two paths force more current into one of them. Over time, the current imbalance between the cells can go to an extreme that forces bits of lithium metal to adhere to the anode. When this happens, the battery is able to store less energy than it is designed to store, meaning a shorter computer run time per charge. And because lithium metal is highly reactive, those scattered bits of metal can fuel a fire if a short crops up and suddenly raises the temperature of the system.

Wiring three cells in a series essentially eliminates that problem [see diagram, "A Not-So-Simple Remodel"]. With only one path for the current to travel, it's easier to control the flow of current, reducing the chance that lithium metal will be deposited, which would compromise the storage capability.

Lampe-Onnerud's batteries don't dramatically lose power in their first six months or so and thus won't need to be replaced as quickly; they are designed to operate at a minimum of 80 percent capacity for three years, the life of a typical laptop computer. After three years of regular use, a traditional lithium-ion computer battery essentially has no capacity left; after a year of typical use, users will find that a battery that once had a 4-hour capacity now has a 2-hour one.

The change in form factor is only one reason for this longer life; she also changed the chemical composition of the cathode from pure cobalt to a cobalt-based mixture; understandably, she won't give out the ingredients of her secret sauce. Jim McDowall, business development manager at Saft Batteries and former chair of IEEE's Stationary Battery Committee, hypothesizes that she selected nickel-manganese-cobalt, a material that potentially fades more slowly than pure cobalt.

Lampe-Onnerud also spent some time optimizing safety systems and control circuitry. McDowall says safety improvements typically come at the expense of energy density, but the extra 14 percent of volume she picked up in the rectangular design may indeed make up for any capacity loss.

The Sonata can recharge faster than traditional batteries, reaching 80 percent of its capacity in 30 minutes—because, Lampe-Onnerud says, the finely tuned design means that more of the current entering the battery goes to charging it instead of heating the table on which it sits.

And that is basically it. "I simplified the system and optimized it," she concludes.

Michael Feinstein, who led Venrock Associates' investment in the company (the size of the first round of investment is not public), said that none of the design changes Lampe-Onnerud made were individually revolutionary. But sometimes a group of evolutionary changes are better than one dramatic innovation.

"I've seen a lot of battery start-ups that do exotic things. And to commercialize them takes a brand-new factory, a huge amount of capital. Christina made a whole series of incremental changes involving the chemistry, the physical design, and the safety mechanisms. When you add them all up, they make a big difference in performance and safety," Feinstein says. And, Feinstein points out, she was careful not to go so far that manufacturing would require a major modification of existing production lines or that the battery wouldn't easily pass qualification tests by potential customers.

Scott Chou, who led the first investment round for Gabriel Venture Partners, said he'd been looking for a start-up doing batteries for several years when he heard about Boston-Power. He'd already rejected battery-technology proposals that increased energy density but sacrificed longevity, changed the form factor and therefore would have a tough time getting industry acceptance, or seemed to have safety issues. He passed on one battery that would vent sulfur dioxide gas when it failed. And then came Lampe-Onnerud.

"Christina offered safety first," Chou said. "Things were not too radically different, which meant that the product was safe and reliable and had a fast time to market. But they were radically improved."

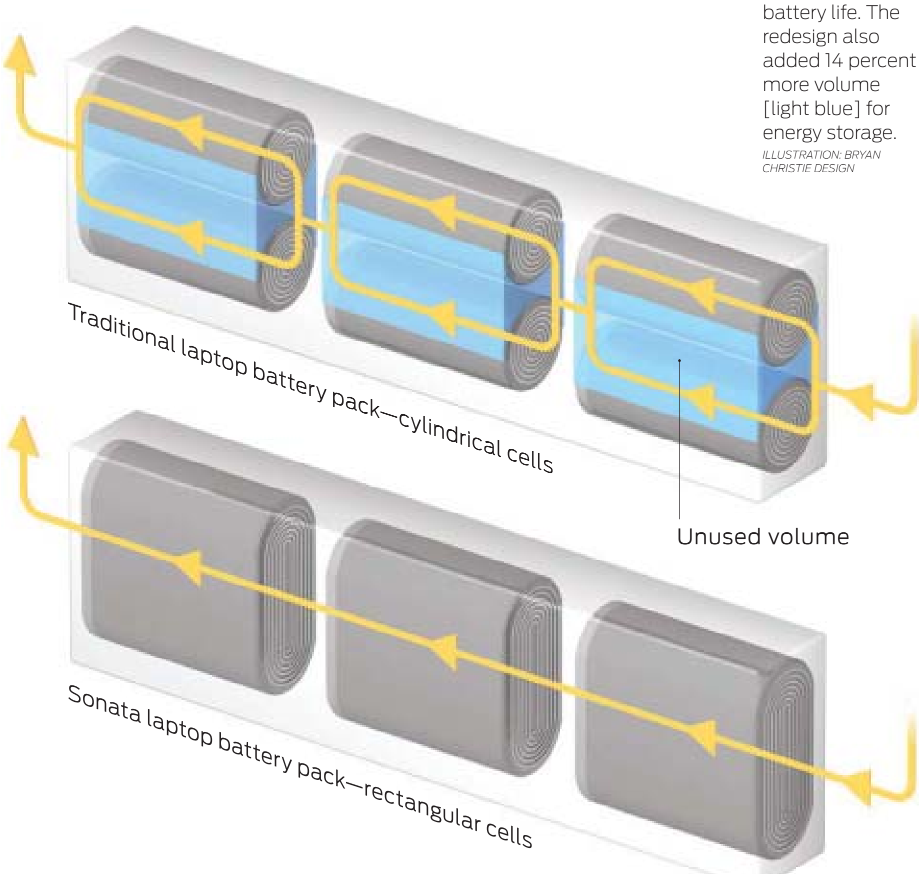
AT THIS POINT, a typical inventor might have taken this new design, built some prototypes, and tried to license the design to established battery manufacturers. As the winter of 2004 arrived, Lampe-Onnerud was thinking she might do that. But the Christmas holidays were approaching, and for Lampe-Onnerud, that meant family time. She and her family went to New Hampshire to ski.

Even on the slopes, she didn't stop thinking about her design. Riding in a chairlift, she announced to her husband, "I have decided to try to be part of the manufacturing process." It would be easier for her to license the design, she reasoned, after proving that the battery was buildable and popular. She also figured that by doing it herself, she could commercialize it faster. And she thought it would be fun. Really. Waiting in lift lines, she began calling friends in China, trying to line up a factory that would let her set up a pilot production facility.

In January, she officially incorporated Boston-Power, with money from two angel investors. One was Anders Barsk, a Swedish investor; the other's identity is not public. She went to China, talked to manufacturers, and signed a deal with Future Power, near Shanghai. By May 2005, the samples coming off the line met U.S. standards for safety and Underwriters' Laboratory requirements. She built a laboratory in her carriage house to test the samples and hired Yanning Song, a recent Cornell engineering graduate, to work there. That lasted until September, when the company that insured her home realized that "a little testing in her barn" actually meant reactive chemicals, heavy machinery, and hundreds of batteries and told her to get the battery operation out, immediately. She moved into a nearby business park. She began filing for patents—15 are in the works so far.

That month she also spoke with former Venrock partner Feinstein. "She talked about the safety features of her design," he recalls, "that if these batteries failed they would just die, not explode. My reaction was, 'That's nice, but you'd better have something else that differentiates you.' She also told me then that safety issues were going to start causing problems for the industry, and my reaction was, 'Sony and Sanyo and the rest are going to build products that break? I don't think so.'"

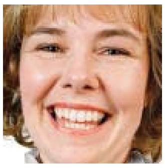
But they did. In June 2006, the famous Dell laptop had a flameout during a conference in Osaka. Then came reports of other battery fires. Sony, the manufacturer of the flaming Dell battery, recalled 10 million units that summer, and other battery recalls followed. And venture capitalists who had already been interested in Lampe-Onnerud's little company were practically pounding at her door.



A NOT-SO-SIMPLE REMODEL: Reorganizing the traditional lithium-ion laptop battery pack for Boston-Battery's Sonata into three rectangular cells connected in a single series [bottom] instead of six cylindrical cells connected as parallel pairs [top] made it easier to control the flow of current, preventing problems that can reduce battery life. The redesign also added 14 percent more volume [light blue] for energy storage.

ILLUSTRATION: BRYAN CHRISTIE DESIGN

IN TYPICAL USE, A YEAR-OLD SONATA BATTERY PACK CAN POWER A LAPTOP FOR 4 HOURS, COMPARED WITH ABOUT 2 HOURS FOR A YEAR-OLD TRADITIONAL BATTERY



CHRISTINA LAMPE-ONNERUD (IEEE Member)

TITLE: Chief executive officer, Boston-Power

GOAL: To cram as much power as possible into a battery without blowing it up

BIRTHPLACE: Ludvika, Sweden

EDUCATION: B.Sc. Chemistry, 1990; Ph.D. Inorganic Chemistry, 1995, both from Uppsala University, Sweden

FIRST JOB: Chorus director

PATENTS: 15

COMPUTER: HP laptop

CAR: Volkswagen Passat

AFTER HOURS: Directs, sings, and records with the Stardust Show Chorus, a 20-woman a cappella group; dances classical ballet and choreographs

She took money from Venrock Associates, Gabriel Venture Partners, and Granite Global Ventures as her first investors; more investment firms contributed later for a total to date of $68 million.

Once she got her new company funded, her husband left Arthur D. Little. The plan was for him to care for the children and the household while she focused on her business. "That lasted five months," Lampe-Onnerud recalls. She then told him that if he really wanted to help her, he should contribute his technical talents. Now he's chief technical officer of the company.

TODAY BOSTON-POWER has 40 employees, many of whom have had a decade or more of experience at places like Duracell, Eveready, Dell, and IBM's ThinkPad division. Boston-Power is no Facebook, staffed by 20-somethings and their dogs; these are people with gray hair and long track records. They don't play foosball all day and pull all-nighters. It's the kind of company where people know their jobs inside and out, they do them quietly, and then they go home to their families for dinner.

But it's no sleepy little tech shop, either. The corporate culture reflects Lampe-Onnerud's vibrant personality and love of music. She selected Sonata as the name for Boston-Power's first battery—which is bright blue, by the way, because that's her favorite color. The conference rooms at the company are labeled Harmony and Symphony; she plans to name the company's next battery Salsa. Employees are a little more dressed up than those at typical start-ups; jeans and T-shirts are not the norm here. Lampe-Onnerud usually wears a suit, always with heels, often with pearls. For her, dressing down is a denim skirt. People are polite to one another and to outsiders. They send thank-you notes whenever someone does something for them. Handwritten thank-you notes. Even to reporters.

SO FAR, tens of thousands of Sonatas have rolled off Boston-Power's first production line in Shenzhen, China; the company is in the process of bringing up a second line in Taiwan. Meanwhile, additional laptop-battery recalls, like the Apple recall late in 2006, and an industry-wide battery shortage exacerbated by a fire in Panasonic's Osaka factory in September 2007, mean that Boston-Power's entrance into the market this year couldn't be at a better time.

Lampe-Onnerud expects at least three major laptop manufacturers to begin shipping units this coming year with Sonata batteries installed. And Boston-Power is negotiating with companies that sell replacement batteries directly to consumers. (Volume prices to manufacturers have not been made public but are reportedly on par with today's premium batteries sold to business customers.) In typical use, a year-old Sonata battery pack can power a laptop for 4 hours, compared with about 2 hours for a year-old traditional battery.

HOW GOOD are the batteries? John Wozniak, Distinguished Technologist at Hewlett-Packard, has been overseeing testing of sample batteries, running them through charge and discharge cycles at different temperatures and under various conditions. HP requires that all batteries it ships with laptops retain at least 80 percent capacity after 300 cycles; Sonata batteries met that mark. Most traditional batteries can't go much past it, but Boston-Power claims that Sonatas can go to 800 to 1000 cycles and still retain 80 percent of capacity; Wozniak is still testing that claim.

If it proves true, Sonata batteries, even with the slight premium on the price that analysts predict, could save HP money, Wozniak explained. These days, savvy commercial customers attempt to return laptop batteries for replacements just before the warranty expires. HP tests the returned units to verify that the batteries have truly failed to perform as expected; if a customer uses the laptop extensively on battery power, it could indeed fail before a year, in which case HP pays for the replacement. Because of the slim margins in today's computer industry, such returns cannibalize profits. With a long-lasting battery, Wozniak said, HP would be able to offer an extended warranty that includes the battery; today's extended warranties don't.

Wozniak also said that in the future, the Sonata battery's ability to fast-charge—that is, get to 80 percent in half an hour—could also be a plus for the laptop manufacturer, but it would take a new generation of computers with design tweaks to take advantage of that feature.

Sonata also passed HP's safety tests, Wozniak said, but "safety isn't something we can sell; it is expected as a given."

If HP does order Boston-Power's batteries, purchasers of HP laptops this year may not know that they are among the first to get Sonata batteries. "We'll do a blind launch," Wozniak says. "The customer won't know what battery is in the product." The company will then be able to calculate from data on product returns whether the Sonata is lasting longer than its competitors.

Lampe-Onnerud dreams that Boston-Power will soon emerge as one of the world's leading battery manufacturers and that the choices she made to make her product environmentally friendly, and to emphasize safety and longevity instead of sheer power, will set a new path for the industry. If that happens, Lampe-Onnerud says, she'll call this venture a success.

"And then," says Lampe-Onnerud, "I will become a singer."

Diana Krall, look out. ❑

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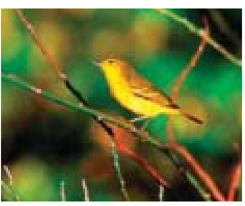
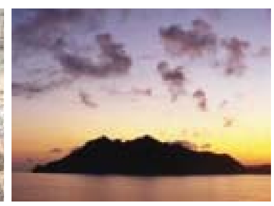
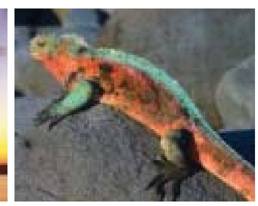
"The archipelago is a little world within itself....
Both in space and time, we seem to be brought somewhat near to that great fact—that mystery of mysteries—the first appearance of new beings on this earth" —CHARLES DARWIN, *THE VOYAGE OF THE BEAGLE*




WIND POWER IN PARADISE

How an international team of engineers brought wind power to the Galápagos Islands

By Erico Guizzo

A gentle breeze blows across the harbor of San Cristóbal, the easternmost island in the Galápagos archipelago. Sea lions bask on the beach under the equatorial sun, and blue-footed boobies dive for anchovies in the Pacific waters. A round brown finch swoops down from a prickly-pear cactus, flutters in midair for an instant, and then lands on my head.

Tens of thousands of tourists come to the Galápagos Islands each year to get close to its extraordinary fauna—to snorkel with hammerhead sharks, hang out with giant tortoises, and have their scalps inspected by Darwin's finches. The archipelago's exquisitely unique creatures gave Charles Darwin a good deal of inspiration for his theory of evolution when he visited in 1835. Nature-loving visitors now flock to the islands in hopes of seeing what Darwin saw.

SINKING SHIP: In 2001, the Ecuadorian tanker *Jessica* ran aground near San Cristóbal, the Galápagos's easternmost island, spilling more than half a million liters of fuel.
PHOTO: MARTIN BERNETTI/AFP/GETTY IMAGES

Ironically, the influx of eco-minded tourists now threatens this island paradise. In particular, the huge demand for electricity to power hotels, shops, and restaurants, as well as the homes of permanent residents, has placed an enormous burden on the islands' power grid, which until recently relied entirely on diesel generators. In 2007, about 5 million liters of diesel fuel had to be shipped in from the mainland to keep the generators running, and demand is growing 10 percent each year.

Seven years ago, after a tanker ran aground and spilled more than half a million liters of fuel into San Cristóbal's harbor, the government of Ecuador, which governs the islands, intensified efforts to free the Galápagos from fossil fuels. A like-minded group of United Nations officials, power engineers, and government representatives came together to devise an energy scheme for the islands, based on renewable energy.

To realize their goal, they had to overcome unexpected technical and logistical hurdles, ease environmental concerns about their project's potential impact on the fragile ecosystem, and cut through the inevitable bureaucratic red tape. There were moments when even the project's leaders feared it would never happen. But this past fall, the team finally installed three enormous wind turbines in the San Cristóbal hills, capable of supplying half the island's electricity.

"This is one of the biggest wind-diesel hybrid projects in the world," says Luis Vintimilla, an Ecuadorian engineer and one of the project managers. "We hope it will be a model for other islands in the Galápagos and elsewhere."

On a serene afternoon last September, I head to the highlands of San Cristóbal with Jim Tolan, an American engineer who, along with Vintimilla, manages the project.

"The place we're going, it's called El Tropezón Hill. I think that means 'big stumble,' so watch out," Tolan quips as we hop into a Chevrolet pickup. "Oh, and grab your rain jacket."

We drive up a dirt road, and the coast's arid, volcanic landscape metamorphoses into steep, grassy hills dotted with *Miconia robinsoniana,* a leafy shrub with purple flowers that you won't find anywhere outside the Galápagos. A dense white mist suddenly engulfs our vehicle. The blue sky disappears, as do the road and the hills. It's like riding through a cloud. Tolan explains that this is the *garúa* season: cold winds and ocean currents cool the air, and a heavy fog and drizzle—the *garúa*—forms in the highlands.

We park, and only after I get out of the truck do I realize we're standing next to a steel tower as tall as a 15-story building, topped by a three-bladed rotor. Two identical towers perch nearby. Erected a month ago and now beginning operation, they are state-of-the-art wind-power turbines imported from Spain. Through the dense fog, I can barely make out the blades—each about the length of a jumbo 747 wing—but I can hear them turning with a thunderous, cadenced whoosh.

The presence of massive wind turbines in the Galápagos may sound incongruous, but as any visitor quickly realizes, the islands are no longer the deserted paradise that first captured Darwin's imagination more than 170 years ago. Today the archipelago, which consists of 13 main islands and numerous islets and rocks, is home to more than 20 000 people, most of whom work in tourism or subsist on fishing and farming. An additional 120 000 visit annually, and that number continues to swell each year.

PREVIOUS PAGES: FROM LEFT: SAN CRISTÓBAL WIND PROJECT; THOMAS R. FLETCHER/ALAMY; REINHARD DIRSCHERL/ALAMY; DAVID HOSKING/ALAMY; GARY CRALLE/GETTY IMAGES; STUART GREGORY/GETTY IMAGES; JACQUES DESCLOITRES/MODIS LAND RAPID RESPONSE TEAM/NASA/GSFC

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One result of all this human activity is a higher demand for electricity. The diesel generators on the four inhabited islands burn some 13 600 L every day. The fuel for the generators, and also for cruise ships and automobiles, arrives by oil tanker from mainland Ecuador. Over the past decade, the number of tankers coming to the islands has jumped from a few per year to a few per month now. For years, conservation experts dreaded an oil spill. On 16 January 2001, it happened.

That night, the Ecuadorian tanker *Jessica* took a wrong turn near San Cristóbal's harbor, rammed into a reef, and ran aground, leaking more than 500 000 L of diesel and bunker fuel. The spill dirtied sea lions and tortoises and killed a handful of pelicans and seagulls. Only a sudden change in ocean currents, which washed the oil out to sea, prevented the spill from becoming an even bigger ecological disaster.

The incident served as a wake-up call. Not long after, the Ecuadorian government decided to invest in renewable energy for the archipelago, and it teamed up with the United Nations Development Programme and the e8—an international consortium of electricity companies that supports energy projects in the developing world—to launch the US $10.8 million San Cristóbal Wind Project.

The goal of the project is to build a 2.4-megawatt wind system that will supply 52 percent of San Cristóbal's annual electricity needs, on average. It might not seem like much, but that means reducing the amount of diesel burned by 950 000 L and preventing 3000 metric tons of carbon dioxide from being dumped into the atmosphere every year. "More important, it should reduce the number of tankers coming to the island," Vintimilla says, "and so, the risks of another spill."

I'M INSIDE WIND TURBINE No. 1, ascending a narrow ladder that stretches upward for 50 meters. Inside this giant white-walled tube, with the fluorescent lights flickering, I almost forget I'm in the Galápagos. It's more like being in a spaceship.

Looking up, I see a pair of legs belonging to José Moscoso, the site's operations manager; below me is Tolan. At the top of the ladder, we unhook our safety harnesses and squeeze through an opening to get inside the nacelle, the turbine's uppermost structure, which houses the generator and holds the blades. Powerful motors can rotate the nacelle so that the blades always face the wind. Made of fiberglass and polyester resin, the 29.5-meter-long blades sweep an area of 2700 square meters in a single rotation, the equivalent of six basketball courts.

The three blades spin at relatively low speeds of up to 25 revolutions per minute. A gearbox ups that rotation to between 750 rpm and 1650 rpm, to drive the 800-kilowatt generator, the heart of the machine. "That's what makes everything possible," Tolan says, pointing to a massive piece of steel and iron the size of a Volkswagen Beetle. "The flow of air becomes the flow of electrons."

The generator produces alternating current whose frequency depends on how fast the wind is blowing and turning the blades, he explains. The electricity then flows into a cable that runs down the tower. Near the bottom, a rectifier converts the ac to dc, which then goes into an inverter for conversion back to ac at the desired frequency of 60 hertz. Finally, a transformer boosts the voltage to 13.8 kilovolts.

Moscoso opens a small hatch in the ceiling of the nacelle and takes a peek outside. How's the view? "*Está toda nublada,*" he says. "It's all cloudy." Tolan tells me that on a clear day you can see almost the entire island and the deep blue Pacific all around. "It's a million-dollar view," he says. "To the south, there's nothing but ocean from here to Antarctica."

AS WE LEAVE El Tropezón, Tolan recalls how he first got involved with the project. He'd been working as a project manager at Industry & Energy Associates, a consulting firm in Portland, Maine. In 2001, Paul Loeffelman, director of environmental public policy at American Electric Power, the e8 member company chosen to lead the San Cristóbal project, called him up. Would he be interested in building a cutting-edge wind farm on a tiny island located 1000 kilometers out at sea, where 85 percent of the land consists of protected national park? Sure, replied Tolan, always up for a challenge.

To navigate Ecuadorian laws

BIG, NOISY, AND SMELLY: San Cristóbal uses three 650-kilowatt diesel generators to produce electricity. The island's new wind system will reduce the amount of diesel burned by 950 000 liters per year.
PHOTO: ERICO GUIZZO

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HEAVY METAL: Workers used five cranes and several large trucks to transport and assemble the wind turbines' 29.5-meter blades and massive tower parts, some weighing more than 30 metric tons.
PHOTOS: DIEGO AÑAZCO

and energy policies, Loeffelman picked Vintimilla, a former director of Ecuador's energy regulation agency. Tolan, a 47-year-old detail-oriented, straight-talking New York City native who graduated from the U.S. Merchant Marine Academy in Kings Point, N.Y., and Vintimilla, a 60-year-old mild-mannered engineer widely respected in Ecuador, made a formidable team.

Vintimilla's first major task was persuading the government to establish regulations for wind-power projects, as San Cristóbal's would be the country's first. Then there was the issue of ownership. The plan was that the e8 would establish a trust entity to manage the project and gradually transfer control to Elecgalápagos, the local electrical utility. "We had to do so many reports for so many different people," Vintimilla says.

In the meantime, Tolan pored over the engineering and financing details. A 2001 study had estimated that a wind system capable of reducing diesel generation by 98 percent would cost $5.4 million. To Tolan, those numbers looked far too optimistic. What's more, since that initial study, annual electricity demand on San Cristóbal had grown from 4950 megawatt-hours in 1999 to 7150 MWh in 2006. Tolan recalculated the project's cost—this time factoring in such details as how many construction cranes you'd need to rent and how much you'd spend relocating *Miconia* plants from the site—and concluded that the project would achieve a diesel reduction of about 50 percent at a cost of some $10 million.

"Everyone was asking me, 'Jim, what did you do?!' " Tolan recalls. He had to explain that the typical costs for a big wind project in the United States—$1000 to $1500 per kilowatt—didn't apply to the Galápagos, where transportation and environmental-related expenses brought the cost per kilowatt to $3500.

Tolan and Vintimilla also had to address concerns from the local community. Wouldn't the turbines disfigure the pristine landscape and hurt tourism? The project managers convinced local leaders that the visual impact would be minor, because the towers wouldn't be visible from town. Moreover, they argued, the idea of renewable energy in the Galápagos would appeal to environmentally conscious visitors, who might even want to go see the towering turbines.

IT TOOK FIVE YEARS for all the pieces—feasibility studies, business and financing plans, environmental licenses, and power-generating permits—to come together, but in September 2006 construction finally commenced. After a groundbreaking ceremony attended by project stakeholders and San Cristóbal's mayor and bishop, Tolan ordered the wind turbines from Madrid-based Made Tecnologías Renovables and told Santos CMI, an Ecuadorian contractor, to start construction at the wind site, which is in a cattle-grazing area outside the national park.

First, though, a pier in San Cristóbal harbor got a 10-meter extension so that it could receive the 5000-metric-ton barges that would transport the wind turbines and construction equipment. The first barge delivered three concrete mixer trucks and a million kilograms of cement, and workers began building the towers' massive foundations.

Tolan planned the schedule so that construction happened early in the year and not during the *garúa* season. But he couldn't anticipate everything. On vacation in Quebec City in April 2007, he was awakened at 3 in the morning by a phone call: the ship sent to the port of Ferrol, in Spain, to retrieve the wind turbines wasn't big enough to accommodate the 30-metric-ton nacelles below deck. Would it be okay to put them above deck, subjecting them to the salty weather of a North Atlantic crossing? Tolan said no. He wanted another ship.

The transportation delay added to a further delay at Ecuadorian customs, but in July 2007 a second barge finally arrived in San Cristóbal with the three turbines and five cranes to install them. Getting all that to El Tropezón was a dramatic operation, with 30-wheel trucks slowly parading through town, the gigantic turbine parts strapped to their backs. Workers ran just in front of the trucks, lifting up low-hanging wires with sticks, clearing people from sidewalks, and even temporarily moving a stone monument that stood in the way.

For the final phase of construction—erecting the 51.5-meter towers—two tubular pieces plus the nacelle were lifted into place by a 400-metric-ton Mantiwac crane, whose own assembly required two smaller cranes. With El Tropezón covered in thick fog, workers radioed careful instructions to the crane operator, who after many hours succeeded in positioning the turbine parts precisely, so that all the bolts lined up. By August 2007, the three turbines had been erected.

Two Spanish engineers look intently at color-coded graphs on a Dell laptop screen. Cristóbal Carrión Pérez and Alvaro Ginel, engineers with Made Tecnologías Renovables, are testing the wind turbines' control system. They have spent most of the last week inside this modest building, in a substation operated by Elecgalápagos, working from dawn until late into the night. They haven't had time to tour the island—or even to take a siesta after lunch.

The San Cristóbal system is a wind-diesel hybrid. The electricity generated by the wind turbines and by three diesel generators converges at this substation before being transmitted to town.

The wind energy arrives at the substation through a 12-km-long transmission line. The 20-year old Caterpillar 650-kW diesel generators are located on-site, inside a concrete metal-roofed building. Exhaust stacks belch their sulfurous fumes into the air, and you have to wear earmuffs because the engines are so loud.

Though smelly, noisy, and polluting, the diesel generation is reliable. Outages happen only sporadically. Still, why not replace the diesel system entirely with wind power? The problem here as elsewhere is that the supply of wind varies quite a bit. When it's very windy, Tolan says, 80 percent of the grid energy might come from wind. "But when there's almost no wind, we might put in very little—or nothing."

That's why San Cristóbal needs to keep the diesel generators running. The diesel system works as a reference, maintaining the voltage and frequency across the grid. And when there's enough wind, the turbines can reduce the diesel generation to 25 percent of its maximum capacity—sometimes one or two diesel generators can even be shut down.

The Galápagos system differs from conventional wind-diesel hybrids in its use of an innovative control scheme developed by Made. In most conventional hybrids—in places like Alaska, Australia, and Vietnam—the wind turbines are always producing as much power as they can. If generation surpasses demand, excess power is stored in batteries; conversely, if wind speeds drop too much and generation falls below demand, the system turns to backup batteries.

The Galápagos hybrid doesn't use auxiliary batteries, which are costly and add complexity to the system. Instead, the turbines automatically reduce or increase their power output according to demand. They do this by adjusting the angle of their blades. At the point where it attaches to the central hub, each blade can rotate, powered by a hydraulic actuator, by small angles up to 90 degrees. The rotation changes the way the blade's surface

INTO THICK FOG: At the height of the construction phase, workers braved foggy and rainy conditions in the highlands of San Cristóbal to build the foundations and erect the wind turbines.
PHOTOS: DIEGO AÑAZCO

FORMIDABLE TEAMMATES: Project managers Luis Vintimilla [above] and Jim Tolan [top right] worked around the clock to keep the construction of the three turbines on schedule.

PHOTOS, CLOCKWISE FROM TOP LEFT: SAN CRISTÓBAL WIND PROJECT; ERICO GUIZZO (2)

is exposed to the wind and thus controls the turbine's overall rotational speed. Each turbine has its own PLC, or programmable logic controller. The PLCs talk to each other through a fiber-optic cable and also monitor the diesel system. If lots of people turn on their air conditioners, for instance, the diesel generators put more power into the grid. The PLCs notice this change, and if there's enough wind, tweak the angle of the turbine blades, speed up their generators, and produce more power to bring the diesel generation back down.

"The three turbines monitor each other and coordinate their power outputs," says Carrión Pérez. "All the three brains talk to each other, but there's no central brain."

On the computer screen, he and his colleagues are fine-tuning the control algorithms to make the turbines' increases and decreases in power output as smooth as possible. The task should take another week or so, and then the turbines can go into commercial operation—and the Spanish will get some downtime.

ARRIVING ABOARD the H.M.S. *Beagle*, Charles Darwin landed on San Cristóbal, then called Chatham Island, on the morning of 17 September 1835. The crater-ridden, sultry, and seemingly lifeless coastline didn't impress the 26-year-old naturalist. "Nothing could be less inviting than the first appearance," he wrote in his journal, first published in 1839 and now known as *The Voyage of the Beagle*. But as he ventured inland, Darwin was surprised by what he found.

On San Cristóbal, Darwin encountered for the first time the archipelago's most famous inhabitants, the giant tortoises. "These huge reptiles, surrounded by the black lava, the leafless shrubs and large cacti, seemed to my fancy like some antediluvian animals," he remarked. Darwin went on to find much more as he explored the other islands during his five-week tour, including 13 types of finch with a "perfect gradation in the size of the beaks," each adapted to a diet of plants, fruits, or insects—the clues for his breakthrough theory scattered before his eyes.

With the high-noon sun beating down, Tolan and I set out to retrace Darwin's first steps on San Cristóbal. The spot where the naturalist is believed to have gone ashore is a tiny bay on the southwestern part of the island. Tolan warns me to beware of the massive, dark-furred male sea lions, which charge if you get too near. I tell him I'm more worried about the marine iguanas, the sharp-toothed reptiles that look like miniature dragons ready to take a bite out of your foot. "Nah," Tolan says, "they're vegetarians."

For an engineer, Tolan has had to learn quite a bit about Galápagos wildlife. Take the Galápagos petrel. Tolan gets just as excited talking about this gray-and-white seabird as he does about power inverters. The petrel nests in shallow burrows in the humid highlands of San Cristóbal and other islands and is one of the archipelago's many endangered animals. Invasive species like rats and cats eat petrel chicks, and cattle destroy their nests. In the last 60 years, the petrel population declined 80 percent.

Studies have shown that wind turbines and transmission lines can kill birds, although there's no agreement on whether the number of dead birds is significant compared with the number of birds killed by other causes such as high-rise buildings and house cats. But in the case of an endangered bird, even a few dead ones are too many. So Tolan convened the Petrel Committee, composed of bird experts from local and foreign organizations, to investigate whether the Galápagos turbines would make the petrel's life even more difficult.

The committee ruled out two potential sites for the turbines because petrels liked to nest in those spots. The group zeroed in on El Tropezón after it found no active nests. But they also had to make sure that petrels didn't fly through the area. The birds are tricky to monitor because they stay out at sea, hunting for food during the day, and returning home only after sunset to feed their chicks.

So the committee dispatched a team of graduate students, equipped with night-vision goggles and microphones. The students hunkered down on El Tropezón and spent their nights looking and listening for petrels. After six months, they concluded that few birds flew where the towers were to be installed.

As we return to town at sunset, Tolan and I meet Francisco Cruz at the Calypso, a colorful bar and restaurant on the promenade off Charles Darwin Avenue. Tolan has hired Cruz, a bird expert who used to work at the Charles Darwin Foundation, to continue to monitor the site. Cruz is also one of the owners of the bar, a business he started with money he earned through his bird work. He calls the investment "petrel dollars."

As we munch on a plate of *patacones*—fried mashed plantains—and sip Pilsener beer, Cruz reports that he and his assistants have found one dead bird. "Not a petrel—something smaller," he says. "It appears it was dead before the turbines were built."

Tolan says the Petrel Committee wasn't just aiming to avoid killing birds; it also saw an opportunity to improve their chances of survival. Profits from the wind project are financing a 20-year program to try to keep rats, cattle, and cats out of the nesting areas. Saving the petrel has involved "a lot of work and resources and money," Tolan says. "But, hey, anything for the birds."

THE ENVIRONMENTAL challenges that the Galápagos face will get only more complicated. The risk of oil spills remains, and as more people flock to the islands, they will inevitably introduce more invasive species. According to the Charles Darwin Foundation, there were 112 invasive species of plants and animals on the islands in 1990; today there are more than 10 times as many.

Three wind turbines will not in themselves solve such problems. Experts say the islands need a better socioeconomic model that makes the local communities part of the conservation process. The United Nations and the Ecuadorian government are both investigating ways to do that, including limiting the number of tourists without hurting the economy. But in terms of reducing the archipelago's and the country's reliance on fossil fuels, renewable energy will play an ever more important role.

"Any measure that we take to diminish the amount of oil circulating between the islands or from the continent to the islands is a good measure," says Cecilia Falconí, an officer at the United Nations Development Programme in Quito. "It's not the size [of the project that matters], but the example. San Cristóbal is the first wind project in all of Ecuador. This is a lesson that all the country will benefit from."

With their work on San Cristóbal nearly completed, Tolan and Vintimilla are already envisioning the next steps. Their idea is to find ways of using the excess wind power the turbines could produce at night, when grid demand is lower. One way to harness that energy is to use special refrigerators that make ice at night and use no energy during the day. Another possibility is to introduce electric scooters and electric cars whose batteries could be charged at night.

But these are plans for the future. Today, sitting on the balcony of the Miconia Hotel overlooking the island's harbor as the barks of sea lions echo in the background, Tolan and Vintimilla prefer to reminisce about what it took to make the project happen. "In 2004, we installed the first wind-metering tower, and I felt something was starting to happen," Vintimilla says. "Now, when I see the spinning of the blades, it's a big emotion." ❏

TO PROBE FURTHER For additional photos and more background information on the wind-turbine project, go to http://spectrum.ieee.org/mar08/galwind.

BIRD WATCH: The organizers of the San Cristóbal Wind Project chose the location of the turbines carefully to avoid areas where the endangered Galápagos petrel flies and nests.
PHOTO: SAN CRISTÓBAL WIND PROJECT

THE RECOMMENDATION SYSTEMS THAT SUGGEST BOOKS AT AMAZON AND MOVIES AT NETFLIX WILL SOON BRING YOU PERSONALIZED NEWS BY GREG LINDEN

PEOPLE WHO READ THIS ARTICLE ALSO READ...

THE NEWSPAPER, that daily chronicle of human events, is undergoing the most momentous transformation in its centuries-old history. The familiar pulp-paper product still shows up on newsstands and porches every morning, but online versions are proliferating, attracting young readers and generally carving out a sizable swath of the news business. In the United States alone, 34 million people have made a daily habit of reading an online newspaper, according to the Newspaper Association of America.

It's just the beginning. Online news will inevitably grow at the expense of its traditional counterpart because the Web not only lowers production and distribution costs, it also opens up newspapers to entirely new formats. Even run-of-the mill Web servers with access to a reasonable supply of news stories can generate thousands of different versions of a newspaper. Yet so far, few newspaper sites look different from the pulp-and-ink papers that spawned them. Editors still manually choose and lay out news stories. Often, the front page changes only once a day, just like the print version, and it shows the same news to all readers.

There's no need for that uniformity. Every time a Web server generates a news page, for example, in response to a reader's clicking on a link, it can create that page from scratch. An online news site can change minute by minute. And it can even generate different front pages, essentially producing millions of distinct editions, each one targeting just one person—you. Unless and until they do so, online newspapers will become increasingly irrelevant as the stories that are important to you get buried in an Internet already filled with absurdly more information than any one person can use.

The most interesting and important way to customize a site is to create a page of stories based on your unique interests culled from informa-

ILLUSTRATIONS: DAN PAGE

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CUSTOM-MADE: Google's "Personalize this page" feature lets you create new categories of news, which then show up in the same left-hand menu that contains its standard categories. In this example, a fan has created a category for news about his favorite musician, Peter Gabriel. Note that Google's algorithms are imperfect; the second news story contains the words *Peter* and *Gabriel,* but the story is not about the musician.

tion about your past reading behavior. There's already a model for that—the recommendation systems used by Amazon, TiVo, and Netflix. Using information on past purchases, movie ratings, or items viewed, these systems steer consumers to items from among the thousands or millions they have on offer. Newspapers can and should borrow this idea.

It could transform the industry. Based on articles viewed, these systems could highlight the ones they think a reader would find most interesting, even presenting them in order, with the most interesting article first. No longer would readers have to skim pages of news to find what they needed. No longer would reporters have to battle for the limited space on the front page.

In their uphill battle to stay relevant, newspapers will first have to catch up with other news sites that already customize their front pages in one way or another. Aggregators such as Google News, My Yahoo, and Netvibes allow a reader to configure the layout of his or her personal page so that it highlights the most popular or highly regarded news. These sites also cluster news by topic or category and let readers focus on the articles that interest them the most. Such innovations are useful, but they still fall short of what's needed. My Yahoo, for example, requires users to configure the page themselves and to make changes when their interests do, instead of accurately inferring those changes from whatever has attracted the user's attention lately.

Google News is the best of the bunch, a popular news site that does use software to automate the prioritizing and laying out of stories. It changes rapidly, clusters stories that focus on the same event, allows users to customize the site, and recommends news based on past reading habits. But news sites could do even better by automatically learning what news stories each reader wants and using that knowledge to "print" millions of personalized editions of the newspaper.

Such features aren't far off—they were actually part of a news aggregation Web site called Findory.com, which I ran between 2004 and 2007. Findory built a unique, personalized front page for each reader, based on what he or she had read in the past. In so doing it showed a way by which newspapers could recommend information much as Amazon recommends books.

Newspapers constitute a US $55 billion business in the United States, yet that business is invariably described as troubled. Many readers still feel loyalty to their hometown newspaper and know it is likely to contain news relevant to them, but they are increasingly reluctant to wade through all its articles to find the few that matter to them. Personalized news recommendations can be a lifesaver to newspapers that are drowning in the sea of information that washes over us all.

IT MAY SEEM A SMALL STEP from recommending products to recommending information. In fact, doing so is actually quite complex. Stand at the entrance of a Wal-Mart or look at Amazon's home page and the shiny world of each one's wares seems limitless. But it's not. It is firmly bounded by the constraints of time and warehouse space. A sprawling Wal-Mart store typically has about 100 000 items; Amazon carries a few million. The world of information, on the other hand, is measured in billions of pages and petabytes of data. Processing data on this scale can require a supercomputer-scale infrastructure well beyond the means of a city newspaper.

Recommender systems also face what is known as the cold-start problem, which stems from the difficulty of rating any item that either has not yet attracted the notice of recommenders or has attracted only those about whom nothing is known. For example, before a new movie is previewed by critics, no one at all has seen it, so no one can recommend it. Within weeks, though, enough people will have contributed opinions to help many others decide whether to see it. But a news article doesn't have weeks to attract attention, only hours. Often, by the time a fair number of people have read the article, it may well have faded into irrelevance. As we'll see, one of Findory's goals was to ameliorate the cold-start problem.

To understand how a really successful recommendation system for news might work, first consider those being used now at sites like Amazon and Netflix. One of the fundamental characteristics of these systems is that they learn not just from your behavior but also from that of other customers. The underlying assumption is that there are other people out there who are like you and that those people have found and enjoyed things you haven't yet seen. These algorithms search over Website logs, ratings, and purchase transactions to discover people with interests similar to your own. Then the algorithms look up the items those people liked and recommend them to you.

Suppose that many people who buy the textbook *Managing Gigabytes* also buy *Lucene in Action*; the algorithm will conclude that the books may be similar, particularly if the people who buy *Managing Gigabytes* buy *Lucene in Action* much more frequently than the general population does. Even if the books are on different topics and the texts of the books are not similar, purchases in common reveal books with similar appeal. People who buy books on information technology may, for instance, also tend to buy science fiction.

More generally, if the recommendation system can find users who have bought many things you have bought, then it will bring to your attention things these other people have bought that you have not. This kind of algorithm is often referred to as collaborative or social filtering because it uses the preferences of like-minded people in the community to filter and prioritize what you see.

Because it's so difficult to apply recommendation algorithms to information, sites have tried to personalize news in other ways. One of the largest customizable news sites, My Yahoo, launched in July of 1996. A user chooses from hundreds of modules—including news, weather, sports scores, and stock prices—and picks the layout of these modules on the page. User-customized sites are simple to build, easy for readers to understand, and take advantage of the ability of online news sites to show a different front page to each reader. By customizing, readers can emphasize the news most important to them.

TO CLUSTER NEWS STORIES, WE HAVE TO DEFINE "SAME EVENT"—AN ILL-DEFINED, SURPRISINGLY HARD PROBLEM

Unfortunately, most readers don't. Research at Yahoo has found that most users do not customize their front pages and that most who do don't bother to update those pages to reflect their changing interests.

Google News, arguably the leading site when it comes to personalized news, goes several steps further, automating things as much as possible. For example, it uses a technique called implicit personalization to recommend different content to each reader, based on the reader's past behavior. It's an innovation that suggests a way forward for the news business. But first, consider how Google News accomplishes two other seemingly simple automation chores: ranking and clustering stories.

Google is, of course, famous for its method of ranking search results. In the case of news, it forms an understanding of which stories are generally the most interesting and important and continually updates a reader's personal home page with that in mind. Google News collects millions of articles from thousands of sources, so it would be out of the question to use a staff of editors to lay out the front page, as most news sites do. Krishna Bharat, who led the development of Google News, says that its algorithm ranks stories according to the authority of the news source, the timeliness of the article, whether the article is an original piece, where the article was originally placed by the editors on the source Web site, the apparent scope and impact on readers, and the popularity of the article.

Google News also clusters stories on the same news event. Clustering gives readers the benefit of diversity, which is particularly useful to readers of international news. For example, a French paper might take a profarmer stance when covering a trade dispute on European Union farming subsidies, while a British newspaper might have a very different view. Another advantage of clustering is that it can either eliminate or call explicit attention to duplicate articles, such as when two newspapers run the same Associated Press wire story.

But the task of clustering news stories on the same event encompasses several subchores, some of them fairly difficult. One of them is simply defining what we mean by "same event"—an ill-defined, surprisingly hard problem. For instance, stories about the escape of a tiger from the San Francisco Zoo last December included articles on how the animal may have gotten free, how it killed a visitor, how it mauled two other people, how it was itself killed by police officers. Are they all the same event?

Google News tackles this problem by using a technique called hierarchical agglomerative clustering. Basically, it puts news articles with similar phrasing together into distinct piles. It starts by analyzing the content of articles to find those that share keywords or key phrases; articles that have enough language in common are assumed to be covering similar topics. The articles in each pile are connected based on the strength of their similarity. To visualize these connections, imagine a treelike structure where the articles are the leaves. If we grab a branch from the tree, the many leaves on that branch are all similar articles—that is, articles about the same general event. Thus a group of leaves near one another on a branch of the tree constitutes a cluster.

This tree is constantly changing. As more and more stories accrue on a general event, the threshold for determining whether any two of those stories are about the same aspect of that event becomes higher. The clusters may shift, with articles jumping out to new groups or old groups that are splitting or combining. The groupings adapt to the news available, which is always changing.

If the ideal result is a newspaper featuring the news you want to see, these clustering and ranking strategies can take you only so far. They can determine whether a new development in a story you've been following is something that might interest you. But they can't make a logical leap—for example, recognizing from your previous interest in articles on the search for extraterrestrial intelligence that you would be fascinated by the discovery of an Earth-like planet in another solar system.

To make this kind of inference requires figuring out an individual reader's interests and accurately recommending new articles based on those interests, just as Amazon and Netflix recommend books and movies. Toward this end, rather than showing top stories of general interest, the Google News recommendation engine attempts to figure out what each reader's top stories should be. The recommender analyzes the past clicks of all readers, the past clicks of the current reader on the Web site, and the currently available news stories and then generates a list of news stories that may be of interest.

Because of the enormous number of articles and users on Google News, traditional clustering methods were impractical. So Google tested three more advanced algorithms for generating news recommendations: MinHash clustering, Probabilistic Latent Semantic Indexing (PLSI), and covisitation counts.

MinHash and PLSI are both essentially clustering methods. That is, they try to group similar items or users. MinHash works by randomizing a numbered list of all possible articles.

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It then finds the first of those articles the reader has seen and gives it a numerical value, called the index, which is simply its position in the randomized list. As it turns out, the probability that two users will have the same index is equal to a statistical measure of their commonality—the items they have viewed in common—which is called the Jaccard similarity coefficient. Given two sets of things (say, magazine articles that two people have read), the Jaccard coefficient equals the size of their intersection (here, the articles both people have read) divided by the size of their union (the articles that either of them has read). The upshot is that by grouping users with the same index value, MinHash can find clusters of similar users.

PLSI is another clustering technique that determines the similarity between users. To visualize its operation, imagine a massive, largely unpopulated matrix where the rows are articles and the columns are readers. You as a reader will have an entry in this matrix on every row that contains an article you've read. PLSI attempts to reduce this matrix to a form that can concisely, albeit approximately, model all combinations of possible users and items. The technique introduces a variable that captures the relationships between items and users. This variable allows you to capture in an algebraic formula the co-occurrences between items and users—the articles they have in common—and in effect forms groups of like-minded users and groups of similar items. These groupings produce the clusters.

The third method that Google News uses, covisitation, is a collaborative filtering algorithm that looks at all the people who've read a given article and then computes the chances that they will also have looked at other articles. This is similar to the well-known "Customers who bought X also bought..." feature on the Amazon Web site.

For each news story and for each reader who clicked on it, Google looks at all the other news stories that the reader has clicked on. Pairs of stories that have a lot of readers in common are considered covisited. Because all the covisited articles are precomputed from historical data, computation on the Web site's database—massive though it is—turns out to be relatively quick and efficient.

Once all the users are lumped into clusters and the list of covisited articles is built, the job of finding articles of interest to any one user is mostly a matter of data lookups. Google News first looks up the clusters for that reader and his or her recently clicked articles and then creates a list of candidate recommendations by using the most popular stories in the clusters and the covisited articles. It then ranks the candidates to determine which will be used for the recommendations.

In a presentation at the 2007 International World Wide Web Conference, Abhinandan Das and two of his colleagues at Google reported that they were able to generate 38 percent more click-throughs with such news recommendations than with a standard list of popular news stories. In other words, the recommendations very clearly helped readers find news of interest to them.

GOOGLE WAS NOT ALONE in coming up with a system for implicit news personalization. A number of companies have worked on the problem, including my own (which proved to be more successful as a research project than as a commercial operation). Findory built a unique front page of news for each reader. We aggregated news and blog articles from thousands of sources around the world and learned each reader's interests from past behavior. Unlike other sites, Findory completely automated the routing of news articles to individual readers; there was no manual customization. A user could change his or her Findory profile only by reading news articles on the site.

When a reader first came to Findory, the Web site started by showing a generic, or default, front page of news, mostly the popular news stories of the day. At the first click on an article, Findory started to change. Reading an article was treated as an expression of interest in that news event. As the clicks continued, the front page drifted further away from the default, quickly filling with articles picked for that reader and building a personalized front page.

For example, if a reader came to Findory and clicked on an article on the U.S. dollar, Findory might add articles on the stock market, oil prices, and the Japanese yen to his or her front page. If the user then clicked on a news article about the value of the U.S. dollar, related articles would be added to the Findory front page, perhaps an article on the euro, another on the Chinese export market, and a third on the price of oil.

Findory's software learned which categories of news and which news sources each reader frequented. For example, if a reader often looked at business stories from *The New York Times*, not only would a prominent link to the *Times* appear but the business section would also be moved to the top of the page, pushing down other categories, such as entertainment or health news.

Findory's software also made it easy to relocate information that the user had found once before. A 2007 study by Jaime Teevan and three other researchers showed that as many as 40 percent of Web search queries are repeats. So Findory kept a history of articles that a user had read recently. It took only a couple of clicks to return to a story a reader had seen a week before.

The core of Findory's implicit personalization of the site was its recommendation engine. We used a hybrid algorithm that combined statistics on what people read with analyses of the content of articles. The first part of the algorithm looked at correlations in reader behavior. Like the Google News covisitation algorithm, Findory's algorithm built a database of "Readers who clicked on X also clicked on Y." When a reader came to the site, Findory retrieved all the articles that the reader had read, looked up other articles that tended to interest the readers who read those same articles, and then reranked and recommended those articles.

Unlike Google News covisitation, Findory's hybrid algorithm didn't ignore the content of an article. The second part of the hybrid collaborative filtering supplemented the data on what articles readers click on with an analysis that primarily looked at sources, keywords, and key phrases to find articles with similar content, on similar topics, or about similar events. For example, if a new reader came to Findory and read an article on a new DSL technology, an article on wireless broadband might be shown because other readers who read that article on DSL also found the wireless broadband article interesting. An article on cable modems might be featured, just because it was new and matched on *broadband* during content analysis, and a story on Internet movie downloading could be shown, both because of reader behavior and because it mentioned broadband.

Such content analysis addresses the cold-start problem. Without it, there is no way to tell who might want to read an article on that tiger that escaped from the San Francisco Zoo; with it, you could make the educated guess that it would appeal to people who live in the Bay Area who have a penchant for animal stories, police stories, and so forth.

Here's how it worked. When a news story first entered Findory, of course no one had read it yet. So Findory fell back to analyzing the content in order to find related articles. In addition, to further acquire click data, Findory would randomly show new articles to some readers to gather more information about them, a process known as exploration.

The goal of Findory's recommendation engine was to use readers to help other readers. When a reader had read an article, Findory automatically shared that article with other readers—that is, Findory interpreted clicking on an article as an expression of interest in it. Readers with interests similar to those of the current reader may thus have been interested in it too. As more people clicked on that same article, the evidence that the article was useful and interesting grew, and Findory would recommend it more broadly.

Findory could be thought of as a social network. Each reader was joined to others by common interests. When a reader found interesting news, the article was shared with just those other readers.

Findory, unlike explicit social networks, did all connections and sharing implicitly. Readers were matched to other readers quietly, behind the scenes. There are two benefits to this scheme. The first is that it maintains privacy—you don't know which readers the system considers similar to you. The second is the way the system is able to reach beyond your network, beyond people you know, to find experts in the community whom you have never met.

NEWSPAPERS WILL HARDLY BE the last step in personalization. The ultimate goal will be to personalize all information. We are deluged by information; we are saturated in it and overwhelmed by it. It is a problem that will only get worse.

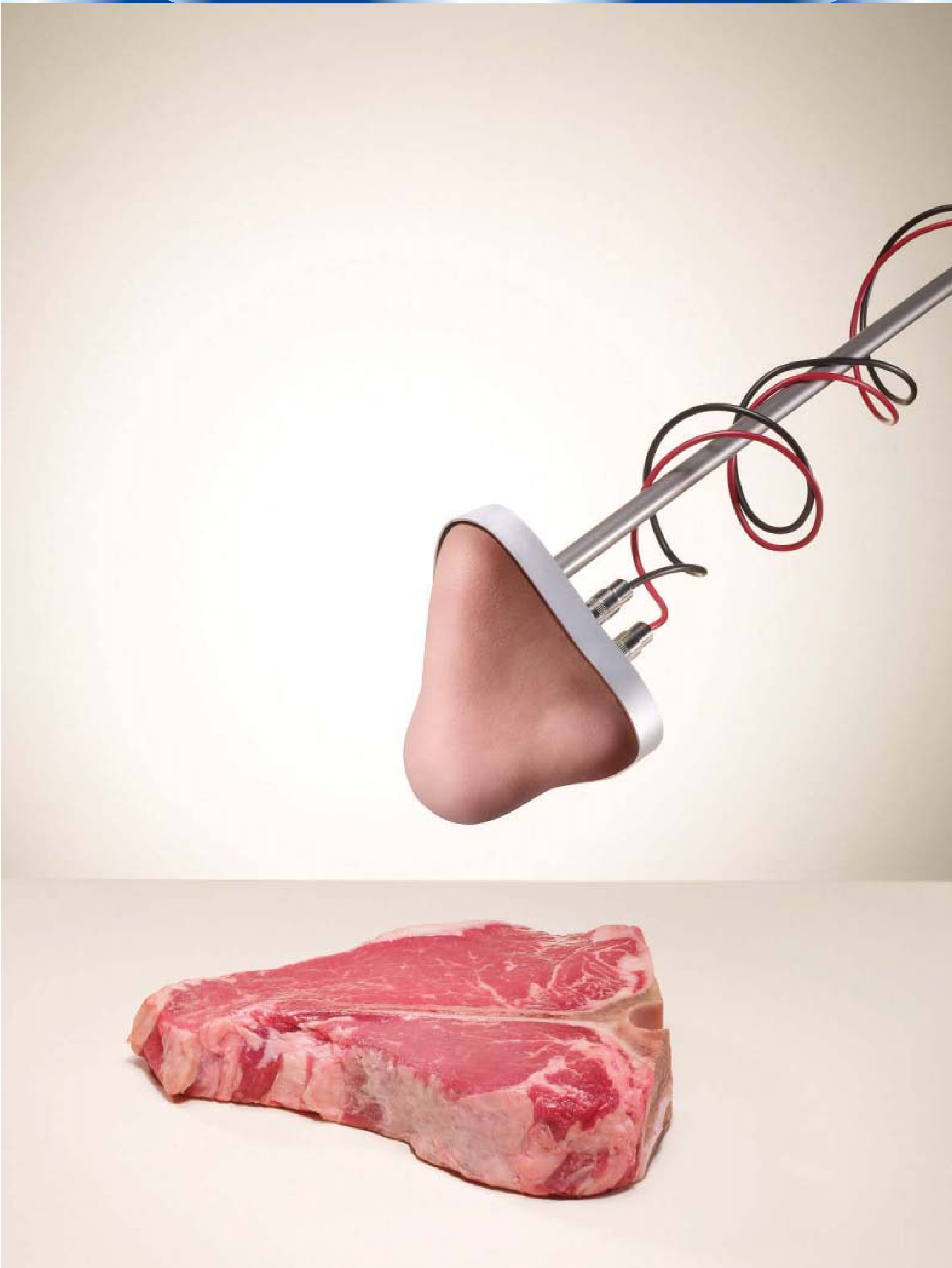
In a world of personalized information, incoming messages would be prioritized by the importance of the contact and the cost of an interruption. All sites, not just newspapers, would organize and order articles according to your interests. Search engines would learn from your behavior, adapt to your interests, and focus on what you need. Ordinary programs, such as e-mail and spreadsheets, would bring to the surface relevant information just when you need it, even without an explicit query. Even advertising would be helpful and relevant.

Building this world of personalized information will require solving problems in machine learning that are particularly hard, given the crushing amounts of data. Computer software will have to scour billions of documents, petabytes of data, and billions of actions by users, learning not only what each person may want but also how and when to bring helpful information to the surface. This software may reside on our desktops, living beside us like a friendly and knowledgeable assistant, burning spare processor cycles in the background to seek out and bring back information we need. Or the software may be located on the Internet cloud, tearing across the supercomputing clusters owned by Google and others, digging through vast volumes of data and ferreting out the knowledge buried there. Either way, the computing power needed will be staggering.

All information sources—including news, messages, advertising, contacts, and Web documents—should be prioritized based on relevance and need. Recommendations and personalization can help by learning from your behavior, adapting to your interests, and providing relevant information instead of leaving you to make a tedious search on your own. ❑

TO PROBE FURTHER The paper by Abhinandan Das and his colleagues, "Google News Personalization: Scalable Online Collaborative Filtering," is available at http://www2007.org/paper570.php. Also worth reading is another paper from the same conference, "A Large-scale Evaluation and Analysis of Personalization Search Strategies," by Z. Dou et al., at http://www2007.org/program/paper.php?id=495.

Two noteworthy papers from other conferences are L. Shih and D. Karger's "Using URLs and Table Layout for Web Classification Tasks" (http://citeseer.ist.psu.edu/shih04using.html) and "Information Re-Retrieval: Repeat Queries in Yahoo's Logs," by J. Teevan et al. (http://people.csail.mit.edu/teevan/work/publications/papers/sigir07.pdf).



ELECTRONIC NOSES SNIFF SUCCESS

E-NOSES WILL SOON BE UBIQUITOUS, THANKS TO PRINTED ORGANIC SEMICONDUCTORS BY JOSEPHINE B. CHANG & VIVEK SUBRAMANIAN

SEVERAL HUNDRED years ago, village doctors in rural China diagnosed diabetes by the characteristically sweet smell of a patient's breath. Today hospitals use a battery of blood tests and laboratory analyses to make that same diagnosis, but doctors may soon be sniffing their patients' breath again. This time the doctors will have electronic noses small and cheap enough to carry in their pockets.

This e-nose will be the culmination of decades of work at countless laboratories, where researchers have sought to create a tiny, cheap, automatic sniffer that would let wine bottles monitor the aging of their contents, allow meat packages to flag spoilage, and enable mailboxes to check for bombs. Imagine barroom coasters that double as Breathalyzers, bumper stickers that monitor car emissions. Until now, it's been just so much sci-fi.

E-nose technology has quietly advanced during the past two decades. Commercial models equipped with sensor arrays came to market in the mid-1990s, and today they're used to distinguish wines, analyze food flavors, and sort lumber. Benchtop systems are also used in the pharmaceutical, food, cosmetics, and packaging industries, while smaller, portable units are used to monitor air quality.

But these noses cost in the range of US $5000 to $100 000. A coming convergence between e-nose technology and advances in printed electronics will finally bring the price down—way down. Within a decade we'll see e-noses that cost tens of dollars and appear in smart packaging for high-end items like pharmaceuticals or as part of intelligent or interactive appliances—picture a refrigerator that knows when milk has gone bad. Prices could easily drop to under a dollar by 2020.

The secret? Conducting polymers. Developers of both electronic noses and printed electronics are exploiting these materials, which can be sensitive to the chemicals that make up odors and are also capable of producing electrical signals. E-nose developers are concentrating on honing the sensing properties of conducting polymers, while the printed-electronics people are investigating ways of using these materials to fabricate ultralow-cost electronics. Combining the fruits of these two separate efforts will finally bring e-noses into our supermarkets, homes, and daily life.

THE HUMAN NOSE is an astounding organ, with millions of odor sensors of hundreds of different types. They let an average adult detect 10 000 different odors, which are usually a complex mixture of vapors, or what chemists call volatile organic compounds. Some arise from chemical concentrations in air down in the parts-per-trillion range. A normally functioning person can tell the difference between fresh milk and milk that's gone bad or walk into a house and notice that it's a pie that's baking, not a turkey, merely by sniffing.

Volatile organic compounds shape the aroma and taste of most foods and can act as keen indicators of freshness and quality. But a fresh-cut orange, say, or a piece of Swiss cheese may release hundreds of these chemicals. As far back as the 1950s, researchers built sensors that could detect and quantify the sprawling assortment of chemical components of an odor. But these sensors were difficult to design and had limited use. Even today, most of these basic chemical sensors operate on a lock-and-key strategy, in which a targeted sensing mechanism picks out one specific kind of molecule from the dozens or more in an odor.

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Your typical e-nose consists of a sampling system, a gas-sensor array, and a signal processor coupled to a pattern-recognition system of some sort. The sampling system brings vapor-laden air into the sensor array; in a laboratory setup it might have a fan that blows air across the array in an action reminiscent of human sniffing. The nose might allow a vial of air to be released inside it; perfume makers capture samples this way. Or it might work passively, simply because the array is exposed, like the sensor in a smoke detector.

In the sensor array, each of the sensors responds to a broad range of gases, with much duplication; multiple sensors will respond to the same gas, but not in the same way, and not to all the same gases. To identify specific odors requires the signal processor to analyze the array response with pattern-recognition algorithms; in today's expensive electronic noses, a microprocessor uses a large set of stored algorithms to sort through patterns. In the future, however, single-purpose noses looking for a simple change—food gone bad, for example—could use application-specific integrated circuits for analysis.

Much like that of the human nose, this type of odor recognition is more flexible and more powerful than what is possible with a lock-and-key sensor, which can detect only a single compound, say, carbon monoxide. Such a sensor would have a hard time telling the difference between Grandma's apple pie and Mom's. But it may be possible to train an array-type e-nose to discriminate between them and all other apple pies.

In 1982, Krishna Persaud and George Dodd at the University of Warwick, in Coventry, England, put together the first sensor array for odor recognition—that is, a collection of electronic sensors, each of which responded in different ways to a range of volatile chemicals. Persaud and Dodd used oscillating semiconducting transducers that changed frequency when they detected certain compounds.

In 1988, Julian Gardner, also at the University of Warwick, dubbed this approach the electronic nose. Rather than cataloging the chemical compounds of an odor, an e-nose identifies complex odors by using pattern-recognition strategies similar to those of the human olfactory system, albeit with different sensing mechanisms. Given a glass of wine, the average person knows from the smell alone what the liquid is. But only a serious oenophile might be able to break the odor down into its constituent parts: alcohols, acids, and esters. The human nose has hundreds of different types of odor sensors, whose response patterns are processed by the brain, which then searches its memory for matches to stored response patterns. An electronic nose uses far fewer sensors; commercial systems have around 10 to 50 sensing elements.

And unlike systems based on lock-and-key sensors, electronic noses can be enormously flexible. Rather than developing one nose for wine monitoring and a different one to detect bad fish, the same piece of hardware could be trained separately for different tasks. Imagine an electronic-nose system shipped with standard pattern-recognition libraries. Load up one for the refrigerator and the system will sniff for spoiling foodstuffs; load up a different one for the garden and the system searches instead for the telltale odors of snails and other pests. And what if you want the e-nose to learn the difference between Grandma's apple pie and Mom's? Well, chances are the manufacturers will have never met Grandma or Mom or sampled the output of their ovens. But they may have included software for generating new pattern-recognition libraries. If so, you would hook up the nose to the training system, introduce it to one apple pie at a time, and find out if the pies generate distinguishable responses in the array. If they do, then generate a new library, load it up, and you've got a personalized apple-pie connoisseur.

MARK HOOPER

In training a nose, it is not necessary to fully understand the chemical differences between good wine and bad wine or between two pies; it is enough that the nose knows. So to teach a nose, a developer simply presents, say, 10 samples of wine gone bad and 10 samples of good wine and asks the system to find a pattern that represents the difference and to use that to distinguish good from bad in the future.

In 1998, the University of Warwick's Gardner along with Philip Bartlett, of the University of Southampton, predicted that "the next decade should see the cost of electronic noses fall dramatically" and that they would "be used not only in industry but also in everyday life." It didn't happen. Today commercial prices for electronic noses are the same as they were in 1998, typically about $10 000. Even simple consumer products like handheld Breathalyzers and carbon monoxide monitors, which usually target only a single compound and are therefore much simpler, sell for $50 and up.

Electronic noses have been expensive up to now because they use different technologies—electronic circuitry for signal processing and pattern recognition along with multiple chemical sensors that have to be separately wired together—and so can't easily be mass-produced. In many cases, a personal computer runs the signal-processing software; the sensing apparatus is simply plugged into it. These patched-together systems have limited uses and aren't suited for high-volume, low-cost consumer markets.

Researchers have tried to integrate the sensors into the circuitry—that is, to make them on a single chip with traditional semiconductor-manufacturing techniques typically using the CMOS process. This is theoretically possible, as sensors are normally made out of metal oxides like tin, copper, nickel, or cobalt oxide; these can be deposited on a wafer. However, a typical CMOS chip has 20 to 40 layers; add in 50 sensors, each with a slightly different composition requiring separate deposition steps, and you've doubled the complexity. In addition to the cost of these extra steps, each layer also introduces defects that hurt yield and therefore raise the cost of each device. And you couldn't manufacture these chips in a multipurpose factory: introducing exotic materials into that environment could hurt yields of traditional chips made on the same line, so you'd have to build your own very expensive manufacturing line. The hurdles for a CMOS e-nose, therefore, are not readily surmountable and have stalled the progress of low-cost electronic noses for years.

Advances over the past few decades in the capabilities of conducting polymers, however, have given e-nose researchers new hope. These materials can be deposited from a solution, enabling them to be cheaply and easily painted or printed onto substrates.

These are organic polymers, which are long molecules with carbon backbones. Carbon, with its four valence electrons, has an enormous capacity for chemical interactions with other materials. This capacity makes organic polymers ideal for sensing applications because they can be designed to interact in many different ways with many different vapor molecules. Most organic polymers are electrically insulating, but by tweaking the structure, designers can produce some electrically conductive polymers by making it easy for charge to travel along the carbon backbone of the molecule.

For a gas sensor to actually "sense" an odor, it must translate a response—which is often a subtle chemical interaction between the sensor and the odor—into an output that can be easily interpreted, such as a color change. Conducting polymers excel at this translation because the chemical interaction between an organic polymer with a vapor molecule can change the polymer's electrical characteristics, resulting in an electrical response that is cheap and easy to detect.

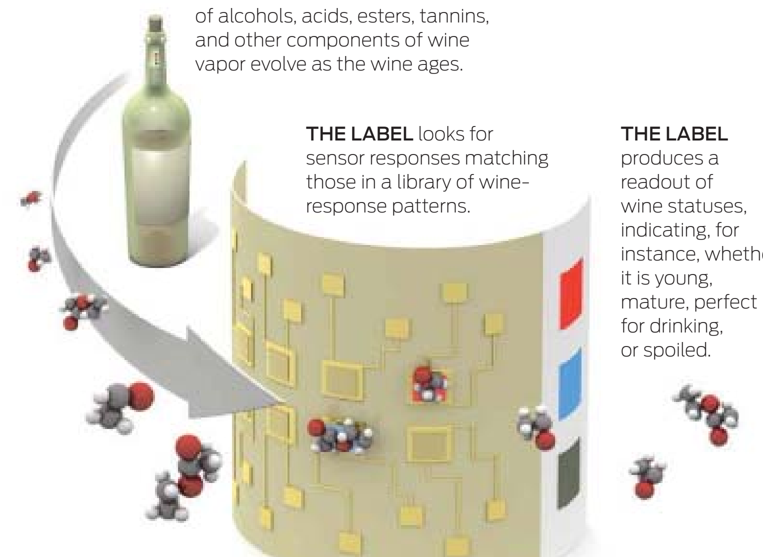
In the early 1990s, scientists first demonstrated that a variety of conducting polymers, each with different electrical characteristics, could be integrated on a single substrate using a process called serial electrodeposition. In this process, the manufacturer repeatedly dips a substrate into a chemical solution containing the chemical building blocks of the sensing polymers. Then an electrical bias is applied, which induces the molecules to polymerize. Polymerization is the process by which many identical small chemical building blocks, called monomers, come together to form long chains.

By slipping low concentrations of different chemicals into the mix during polymerization, scientists can modify the characteristics of the final polymer. Using this method, only one type of material can be deposited at once, so manufacturers must repeat the process multiple times to get different polymers onto the same substrate.

While conducting polymers are potentially soluble, the major-

USING ELECTRONIC-NOSE technology, a label of the future sniffs a fine wine, monitoring the evolution of its contents as it ages. The device, manufactured by printing conducting polymers on a flexible substrate, will use a sensor array and pattern-recognition algorithms to differentiate between young wines, mature wines, and spoiled wines. Developers will generate a reference library of patterns by exposing the nose to a vast variety of wines at each of the different stages and having it look for distinctions among the stages.

ILLUSTRATION: BRYAN CHRISTIE DESIGN



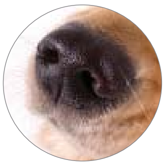
THE RELATIVE concentrations of alcohols, acids, esters, tannins, and other components of wine vapor evolve as the wine ages.

THE LABEL looks for sensor responses matching those in a library of wine-response patterns.

THE LABEL produces a readout of wine statuses, indicating, for instance, whether it is young, mature, perfect for drinking, or spoiled.

ODOR MOLECULES in the wine vapor interact with an array of gas sensors, eliciting an electrical response.

THE AVERAGE human being is able to recognize approximately 10 000 different odors.



MOST DOGS' noses are approximately 100 000 to 1 million times as sensitive as a human's.

SALMON USE their sense of smell to identify and return to their home-stream waters.

ISTOCKPHOTO (3)

ity of conducting polymers used for sensing today are not. The advantage of going to soluble polymers is that manufacturers already have tools for laying soluble polymers on a substrate cheaply, reliably, and quickly. They print them the same way an inkjet printer quickly deposits various colored inks to make color printouts. Printing allows the placement of many types of different materials next to one another on the same substrate. In printed sensors, then, additional sensor materials can be incorporated by adding extra print heads; additional process steps are not required. Processes like these have jump-started the emerging field of printed electronics, with the first new products, like e-books by Sony and Amazon, just now reaching consumers. Also, printing is compatible with roll-to-roll processing, in which sheets of substrate are continuously processed, as opposed to processes such as electrodeposition, in which small samples of the substrate must be dipped individually into different batches of solution. The roll-to-roll method speeds up manufacturing considerably, which brings down the cost.

Printing polymers doesn't completely solve the manufacturing problem for e-noses, however. It is very rare to find the properties of conductivity, sensitivity to vapors, and solubility in a single organic polymer material. To get around this, researchers can incorporate conductive non-sensing materials into a soluble, sensing—but nonconductive—polymer. Visualize a pudding with raisins in it. Conductive raisins are suspended in a pudding that swells in the presence of certain odors. At a sufficiently high raisin density, randomly adjacent raisins would begin to form complete paths through the pudding to allow charges to percolate through. Carefully adjust the raisin density to rest near this threshold and you can expect any expansion or contraction of the pudding to strongly affect the number of percolation paths through the pudding.

There are two different types of "raisins" that developers use to form these soluble, conductive polymer composites. One is carbon black, which is made up of conductive carbon particles small enough to suspend easily in a soluble polymer solution. The other is polypyrrole, a common soluble, conductive polymer.

RESEARCHERS ARE testing methods of using these polymer composites to print sensor arrays along with support circuitry on an integrated circuit chip. Electronics manufacturers have been developing techniques for printing organic electronics for a decade at least, focusing on printed displays, memories, batteries, organic thin-film transistors, and photovoltaics. Printed electronics in some of these applications are nearing their last stages of development before commercialization. Although many of the organic conductive materials used in these applications are similar to those used in e-nose research, no developer has yet reported printing organic electronics for low-cost gas-sensor arrays.

In 2006, researchers at the University of California, Berkeley, reported using an array of integrated print-

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

able organic semiconductors to differentiate between basic classes of odors, such as acids, alcohols, amines, and thiols; for example, this sensor array was able to distinguish wine from vinegar. In October 2007, researchers at MIT announced that they had successfully printed barium carbonate, which can detect a range of gases, onto a silicon chip. This is yet another printable sensing material that could enable printed gas-sensor arrays, though it has yet to become part of a working e-nose system.

The main hurdles to wide commercial use of these organic polymers involve their instability and short lifetimes. For odor sensing, a stronger chemical interaction between the sensor and the vapor improves the sensitivity of the sensor. However, the stronger the interaction, the more likely that the interaction will not be completely reversible. Put another way, the complete reversibility of the sensing interaction prolongs sensor lifetime, because the sensor is not permanently changed by the odors.

The most stable organic materials are the ones that do not interact with the environment at all. But no interaction means no sensing, of course. So gas sensors based on organic electronics must balance chemical sensitivity with resistance to degradation. Fortunately, there are a multitude of ways to tweak the properties of organic electronic materials to find the balance. Because the carbon atoms in the backbone of these substances bond easily with other materials, researchers can tack on or take off atoms of oxygen, nitrogen, or sulfur, for example, and change the shape, electrical response, or other properties of the polymer.

Making such changes has let researchers build electronic circuits that are sensitive to various gases. "Chemiresistors" change resistance in response to certain vapors, "chemicapacitors" change capacitance, and "chemitransitors" exhibit a variety of electrical changes in response to a particular vapor. As designers can also create standard resistors, capacitors, and transistors using organic electronics, they could incorporate sensing and signal processing into a complete e-nose package that could be manufactured cheaply.

It will take perhaps a decade more to increase the performance, yield, and reliability of organic electronics in order to make a cheap electronic nose a reality. Sensitivity, selectivity, and reproducibility of printable sensors all need improvement. Applications with lower cost margins, such as monitoring perishable items at the grocery store, will require aggressive refinement of ultralow-cost printing techniques. More critical applications, like disease diagnosis, would require stringent improvements in accuracy and reliability as well as rigorous field testing. But once the technology is ready, printed electronics could do for e-noses what the printing press did for books: it could allow them to go from rare to ubiquitous in the blink of an eye...or the sniff of a nose. ❑

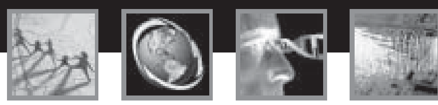
TO PROBE FURTHER To learn more about printed electronics, visit http://www.printedelectronicsworld.com.

For more information about electronic noses, see Electronic Noses: Principles and Applications, *by J.W. Gardner and P.N. Bartlett, Oxford University Press, 1999.*

For a description of the printable organic semiconductor sensor array demonstrated at the University of California, Berkeley, see "Printable Polythiophene Gas Sensor Array for Low-cost Electronic Noses," Josephine B. Chang, Vincent Liu, Vivek Subramanian, Kevin Sivula, Christine Luscombe, Amanda Murphy, Jinsong Liu, and Jean M. J. Fréchet, Journal of Applied Physics *100, 014506 (2006).*

INRS

Science in ACTION *for a world in* EVOLUTION



TENURE-TRACK FACULTY POSITION (PROFESSOR-RESEARCHER) IN TELECOMMUNICATION

Competition: DS 08-01

Within the framework of its Énergie, Matériaux et Télécommunications (EMT) centre's strategic research programs, the Institut national de la recherche scientifique (INRS), a world-renowned university centre with programs at both graduate levels (M.Sc. and Ph.D.), is inviting candidates to apply for one tenure-track faculty professor-researcher position in the following areas:

- Networks;
- Wireless communications;
- Optical/photonics communications;
- Speech processing, image processing, multimedia signal processing.

PLACE OF EMPLOYMENT

INRS-Énergie, Matériaux et Télécommunications, Montréal (Québec)

WORKING LANGUAGE

French is the working language. Knowledge of English would be an asset.

SALARY

Salary and benefits are in accordance with the current collective agreement at INRS.

All applications will be treated confidentially. Interested applicants should forward a complete curriculum vitæ by e-mail and registered mail, a copy of their 3 most representative publications, a 1 to 2 page description of their research interests, as well as the names and addresses of 3 references before **May 15, 2008**, indicating competition DS 08-01 to:

Director
INRS-Énergie, Matériaux et Télécommunications
800, de La Gauchetière Ouest, suite 6900
Montréal (Québec) H5A 1K6

concours@emt.inrs.ca

For further information, please visit our Web site at:
www.emt.inrs.ca

INRS adheres to the principle of work equality.
In accordance with Canadian immigration laws, Canadian citizens and Permanent residents will be given priority for this position.

Université du Québec
Institut national de la recherche scientifique

www.inrs.ca

FACULTY POSITIONS
Department of Electrical and Computer Engineering

Southern Illinois University Carbondale

The Department of Electrical and Computer Engineering invites applications for three faculty positions, at the rank of Assistant Professor, one in each of the following three areas:

(a) Microelectronics with emphasis on Digital VLSI Circuit Design

(b) Software Systems with emphasis on Real-Time Embedded Systems, Embedded Software or Software Engineering

(c) Communications and Networking.

Applicants must have a Ph.D. degree (at the time of appointment) in Electrical Engineering, Computer Engineering or a related field, a demonstrated ability for excellence in teaching and potential for high quality research documented by technical publications. Individuals currently working toward their Ph.D. degree and expecting to graduate by August 15, 2008 will be considered for interview. Department provides support and excellent opportunities for the development of new faculty. Consideration of applications will begin on March 16, 2008 and will continue until position is filled. Effective date of employment is August 16, 2008.

Applicants should submit a resume, a list of three references, a statement regarding the specific area of interest and Statement of Goals to the Chair of the Search Committee, Department of Electrical and Computer Engineering, Mail Code 6603, Southern Illinois University Carbondale, 1230 Lincoln Drive, Carbondale, Illinois 62901.

SIUC is an affirmative action/equal opportunity employer that strives to enhance its ability to develop a diverse faculty and staff and to increase its potential to serve a diverse student population. All applications are welcomed and encouraged and will receive consideration.

中山電機

National Sun Yat-sen University
Department of Electrical Engineering
FACULTY RECRUITMENT

Department of Electrical Engineering at National Sun Yat-sen University (NSYSU) invites applications from outstanding candidates for faculty positions (Assistant Professor, Associate Professor, or Full Professor). Applicants of all areas in electrical engineering are welcome. However, applicants with (1) Control and (2) Power related specialties/applications are most preferable.

Applicants should have a Ph.D. degree in electrical engineering or other related fields. Responsibilities include effective teaching at the undergraduate and graduate levels, and establish a strong research program that involves supervision of graduate students and acquisition of research grants.

Applicants should send, before March 31, 2008, (a) a curriculum vitae, (b) transcript (for fresh Ph.D. applicants), (c) three recommendation letters, (d) publication list, (e) reprints of selected papers, (f) a statement on teaching and research plans, and (g) other supporting material to the following address:

Faculty Search Committee
Department of Electrical Engineering
National Sun Yat-sen University
Kaohsiung, 80424 Taiwan
E-mail: **chiaying@mail.ee.nsysu.edu.tw**
Phone: +886-7-5252000 ext. 4103 Fax: +886-7-5254199
URL: **http://www.ee.nsysu.edu.tw**

NSYSU has been named by Ministry of Education (MOE), Taiwan, R.O.C. as one of the top seven research-intensive universities in Taiwan since 2002. It is also one of the 12 universities at Taiwan that have just been awarded the total 5-year, 50-billion NT$ special development fund from MOE. The EE department is consistently ranked among 5 of the best EE programs in the nation, and is the only university in Taiwan with full scholarship support program for International Master of Electric Power Engineering.

IBM

IBM Systems and Technology Group (STG) is looking for Exceptional Talent in the areas of Compact Modeling, ASICs and Processor Development for its facility in Bangalore, India.

*IBM Systems and Technology Group (STG) is the world's premier hardware and systems development organization and has sustained its technology leadership position over the years of silicon revolution. The sustained leadership is a testimony to the IBM core values of innovation, dedication, trust and customer satisfaction. IBM's semiconductor technologies include SOI, Bulk CMOS, RFCMOS, HV CMOS, and SiGe HBT BiCMOS Technologies. The IBM STG centre at Bangalore is responsible for Processor development, ASIC methodologies, EDA development, compact models (e.g. spice models), process design kits (PDK), leading edge computational lithography, functional characterization support, design and modeling for nanoscale devices. For more information about IBM's leadership in semiconductor technologies, please visit **www.ibm.com/chips**.*

Opportunities

COMPACT MODELING ENGINEER: Develop compact models for active and passive (both FEOL and BEOL) devices in advanced CMOS, mixed signal, and RF technologies. Work closely with device engineers to define parameter targets. Define test programs for DC and RF device measurement and characterization. Use software such as ICCAP to extract parameters for BSIM, PSP or other models. Qualified candidates must possess a MS or PhD in Electrical Engineering or Physics and strong knowledge of semiconductor devices.

PARASITICS EXTRACTION ENGINEER: Create input files for different technology stacks, BEOL ground rules and determine effects of parasitics on device and circuit performance. Job includes mapping LVS to PEX layers, creating and building test structures to verify accuracy of the PEX decks as compared to a reference 3D EM solver. MS/MTech or PhD in Electrical Engineering or a related area required. Candidates should have knowledge of electromagnetic theory, experience in Cadence design system or other standard tools and Perl/Shell scripting.

DESIGN AUTOMATION ENGINEER: Needed candidates both in DRC and LVS areas. DRC/LVS Engineer will develop Design Rule Checking (DRC) and Layout vs. Schematic (LVS) decks in EDA tools to match IBM's leading edge technologies. Implement Tvf or Tcl macros in the code. Develop code for proximity effects, T-Lines, PC/RX corner rounding etc. BS/B.Tech or specialized diploma and minimum 5 years industry experience required.

DATAPREP ENGINEER: Function in roles such as a Boolean Developer, Infrastructure Developer, and/or Layout Test Engineer. Candidate should have experience in shape manipulation, basic layout editing skills on industry standard layout editing tools, and experience with tools such as Mentor Calibre, SVRF, or Cadence Virtuoso. Hands-on experience needed with CAD tools, good scripting skills, testing methodologies. Software skill requirements are C, Java, Perl, Scripting language such as Kornshell.

OPC/ORC DEVELOPER: Develop software infrastructure using physical verification tools, interact with integration, design teams to provide optical proximity corrections on design patterns and improve manufacturability. Fix ORC/MRC issues as they arise. In-depth knowledge of reticle enhancement techniques with exposure to 65nm, 45nm technologies. Develop OPC runset coding, optimization, regression and testing. Interface with lithography, integration, design teams. Experience with Mentor Calibre SVRF, Cadence Assura, and/or Cadence Virtuoso, software skills such as C / C++ coding, shell / TCL / Perl scripting, object oriented programming a plus.

For both Dataprep engineer and OPC/ORC developer positions, qualified candidates must possess a Degree BS/BTech or MS/MTech in Computer Science, Electrical Engineering or related fields.

ATOMISTIC/QUANTUM EFFECTS MODELING ENGINEER: Involves theoretical understanding of quantum effects in 22 nm scale devices; these include carrier transport, geometry and material dependent bandstructure calculations, role of metal and high-k material interfaces, and related phenomena to enable development of 22 nm scale devices.

TECHNOLOGY CAD ENGINEER: Involves the improvement and development of an IBM proprietary tool for the simulation of leading edge semiconductor devices. In particular, physical and numerical models for carrier transport influenced by e.g., channel materials, strain, high-k materials, and crystallographic orientation will be developed and implemented.

Candidates for Atomistic modeling and Technology CAD positions should have a strong background in semiconductor physics, quantum effects in nano-devices, numerical programming, and computer programming in mixed language environment and possess a PhD/MS in Physics/Materials Science, Electrical Engineering or Computer Science.

DEVICE CHARACTERIZATION ENGINEER: Analyze electrical test data to monitor and drive improvements in device performance, line centering, and variability. Responsibilities include statistical and exploratory analysis of test data, overall ownership of the test plan including selection of key test structures and setup.

DEFECT CHARACTERIZATION ENGINEER: Monitor, analyze and drive improvements in random and systematic defect densities, line resistivity centering and variability. Interface with Process Integration Development.

FUNCTIONAL CHARACTERIZATION ENGINEER: Analyze product level data from fabricated chips and suggest improvements to yield/performance /design. Interface with internal and external customers to communicate status, drive changes.

Qualified candidates for all characterization positions, should have a basic understanding of semiconductor device physics and operation, solid programming skills and familiarity with data analysis and characterization methods with a BS/BTech, MS/MTech or PhD degree in Electrical Engineering or Computer Science, Material Science or Physics.

For all below positions qualified candidates should have an MS/M.Tech. or Ph.D. degree in Electrical Engineering or Computer Science and relevant domain experience.

NANO KERNAL ENGINEER: Analyze and develop nano-kernel for validating new advances in IBM processors. Responsibilities include development, testing, validation and performance analysis of processors and nano-kernal used for the hardware validation.

SRAM/ IO DESIGN R&D ENGINEER: Develop circuit designs for SRAM, Register files and IO blocks. Responsibilities include development, verification and interface with the other geographies for ASIC/ Processor development.

CELL LIBRARY DEVELOPMENT ENGINEER: Develop BLAS, LAPACK and Mathematical library routines for the Cell Processors. Responsibilities include development, verification, analysis and performance optimization of library routines.

IP MAINTENANCE LEAD: Enhancement and maintenance of existing ASIC and Processor IPs and porting them to new and evolving technologies. Responsibilities include leading a team of IP maintenance engineers, interfacing with customers and managing requirements, schedules and deliverables.

IP TEST LEAD: Testing of existing ASIC and Processor IPs and porting the verification platform to new and evolving technologies. Responsibilities include leading a team of IP test engineers, interfacing with customers and managing requirements, schedules and deliverables.

LOGIC DESIGN/VERIFICATION ENGINEER: Development and verification of Architecture, High level design and front end RTL development of ASIC/ Processor modules. Responsibilities include Development, reviews, verification and interfacing with customers.

LOGIC DESIGN/VERIFICATION LEAD: Development and verification of Architecture, High level design and front end RTL development of ASIC/ Processor modules. Responsibilities include leading a team of Logic design and verification engineers, reviews, interfacing with customers and managing requirements, schedules and deliverables.

PROCESSOR CUSTOM LAYOUT ENGINEER: Design and verification of full custom layouts for processor modules. Responsibilities include development of full custom layouts and interfacing with circuit design teams in multiple geographies.

Sr. PROCESSOR CUSTOM LAYOUT ENGINEER: Design and verification of full custom layouts for processor modules. Responsibilities include leading a development team of custom layout engineers, reviews, interfacing with circuit design teams in multiple geographies and managing requirements, schedules and deliverables.

PROCESSOR SEMI CUSTOM LAYOUT ENGINEER: Design and verification of layouts for processor modules using semi custom tool flow. Responsibilities include development of macro layouts, interfacing with circuit design and tool development teams in multiple geographies.

Sr. PROCESSOR SEMI CUSTOM LAYOUT ENGINEER: Design and verification of layouts for processor modules using semi custom tool flow. Responsibilities include leading a development team of semi custom layout engineers, reviews, interfacing with circuit design and tool development teams in multiple geographies and managing requirements, schedules and deliverables.

ASIC DEVELOPMENT LEAD/ MANAGER: Development of EDA processes and methodologies for ASIC development. Responsibilities include leading and managing a development team of ASIC flow development engineers, reviews, interfacing with customers and managing requirements, schedules and deliverables.

CHIP PD LEAD/ MANAGER: Development of complete ASIC from net-list to GDS II. Responsibilities include leading and managing a development team of ASIC physical design engineers, reviews, interfacing with customers and managing requirements, schedules and deliverables.

Please address your queries/resumes to Neha Pareek. Email: nepareek@in.ibm.com. Please quote 'IEEE Spectrum' in the subject line along with the position you are applying for.

Lecturer/Senior Lecturer/Associate Professor/Professor in Multimedia Content Creation including Computer Graphics and/or Computer Music

School of Engineering and Advanced Technology

Wellington

A new academic vacancy in the School of Engineering and Advanced Technology (SEAT), Massey University Wellington campus is available for a qualified candidate to support the development and delivery of the Multimedia Systems Engineering major of the four-year Bachelor of Engineering with honours program.

Closing date: 30 March 2008 Reference number: A035-08B

Lecturer/Senior Lecturer/Associate Professor/Professor in Multimedia Signal Processing and Multimedia Communications

School of Engineering and Advanced Technology

Wellington

A new academic vacancy in School of Engineering and Advanced Technology (SEAT) Massey University Wellington campus is available for a qualified candidate to support the development and delivery of the Multimedia Systems Engineering major.

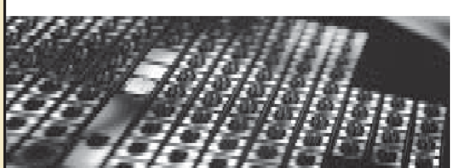
Closing date: 30 March 2008 Reference number: A036-08B

For further information and to apply online, visit: **http://jobs.massey.ac.nz**

www.massey.ac.nz
0800 MASSEY

Te Kunenga ki Pūrehuroa

Massey University



DTU

SENIOR RESEARCHER

WITH MANAGER DUTIES FOR DEVELOPMENT OF SMART ELECTRIC POWER TECHNOLOGIES

Department of Electrical Engineering seeks a senior researcher for smart sustainable electric power systems and future electric technologies at our Center for Electric Technology. The position implies research in a selected field based on the applicant's personal profile and interest as well as a special assignment regarding management of the centre.

Further information may be obtained from Professor Jacob Østergaard, e-mail: joe@oersted.dtu.dk

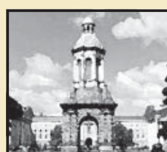
The full text of the announcement can be seen on DTU's homepage.

Application deadline: 17th March 2008 at 12.00.

The Technical University of Denmark is one of the leading technical research and educational institutions in Northern Europe with 6.200 students, 4.500 employees and a yearly turnover of DKK 3.1 billion.

As of January 1, 2007 DTU has merged with the Danish Institute for Food and Veterinary Research, Risø National Laboratory, the Danish Institute for Fisheries Research, the Danish National Space Centre and the Danish Transport Research Institute.

Further details www.dtu.dk/vacancy



TRINITY COLLEGE DUBLIN
The University of Dublin

www.tcd.ie/vacancies

Centre for Telecommunications Value-Chain Research (C.T.V.R.)

ctvr

Research Professor in Network Architecture

The Centre for Telecommunications Value-Chain Research works actively in both optical and wireless networking, and to increase our competence in network architectures we are initiating a Research Professorship in Network Architecture.

The successful candidate will be engaged in the current re-examination of internet architecture and will be actively exploring its likely successor. The appointee will be expected to avail of selected Science Foundation Ireland programmes tailored for this position, to establish a research team and to quickly establish an international research presence in this field. It is further expected that the post-holder will work within the Centre for Telecommunications Value-Chain Research (http://www.ctvr.ie/) and will play a key leadership role in its Emerging Networks strand.

For further information on this Centre please see www.ctvr.ie

A full job description and application details for this position are available at www.tcd.ie/vacancies

Closing date will be no later than 12 noon on Monday, 31st March, 2008.

Trinity College Dublin is an equal opportunities employer.

國立臺北大學 National Taipei University

A Faculty Position in Graduate Institute of Electrical Engineering

The Graduate Institute of Electrical Engineering invites applications from outstanding candidates to fill one tenure-track faculty position at all ranks in the fields of System-on-Chip (including digital, analog, RF and bio-electronics), EDA and embedded systems. An earned doctorate degree in Electrical Engineering or equivalent degree in a closely related field is required. Qualified candidates should have a strong commitment to research, and to teaching graduate courses. Screening begins from now and the due day of applications is March 17th, 2008.

Visit
http://www.ntpu.edu.tw/college/e6/ee/www/indexc.html
for further information.

Applicants should submit: (1) a curriculum vitae, (2) samples of recent publications, (3) photocopy of Ph. D. diploma (fresh Ph. D. should provide it by June 1st, 2008), (4) two recommendation letters, (5) transcripts of all post graduate work (for assistant professorship applicants only), and (6) statement of research, to the following address:

Graduate Institute of Electrical Engineering
National Taipei University
151 University Rd., Sanshia,
Taipei County (237)
TAIWAN
E-mail: **chey039@mail.ntpu.edu.tw**
TEL: +886-2-8674-6474
FAX: +886-2-2673-6500

School of Electronic, Information and Electrical Engineering (SEIEE)

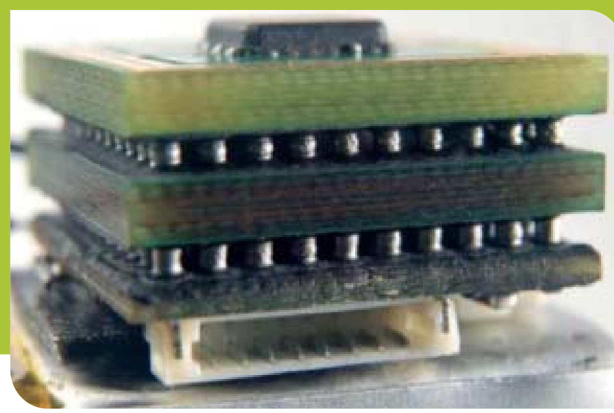
Shanghai Jiao Tong University (SJTU)

FACULTY POSITIONS Shanghai Jiao Tong University (SJTU) School of Electronic, Information and Electrical Engineering is seeking applications for faculty positions at all ranks with emphasis on the Associate Professor level. The School has five Departments which are Automation, Computer Science and Engineering, Electrical Engineering, Electronic Engineering, and Information Measurement Technology and Instruments, respectively, and every Department is looking for new faculty members. Qualified candidates with recent Ph.D. degrees are especially encouraged to apply and will be hired directly at the Associate Professor level if successful. Annual salary is highly competitive among all the Chinese Institutions which ranges between 120,000-180,000 RMB for Associate Professor, and 220,000 to 250,000 for Full Professor and commensurates with experience and qualification.

Further information about the School can be found at **http://www.seiee.sjtu.edu.cn**. Applications including curriculum vitae and contact information of three references should be sent electronically to:

Prof. Xiaofan Wang
Associate Dean
School of Electronic, Information, and Electrical Engineering
The Shanghai Jiao Tong University
800 Dongchuan Road
Minhang, Shanghai 200240
The People's Republic of China
e-mail: xfwang@sjtu.edu.cn
Applications will be reviewed until all the positions are filled.

3D technology to give our future a whole new dimension?
>> Let's turn tomorrow into today.



IMEC's roadmap for 3D technology development explores the possibilities to interconnect active devices in different 2D planes, a choice that also affects system design in a significant way.
IMEC's 3D research program aims to understand and exploit novel 3D technologies and to limit 3D integration cost. Both the 3D technology and design subprograms are based on the requirements for functionality, cost, testability and power of actual advanced systems, as they are studied by research groups at IMEC.

Are you ready to work on groundbreaking projects like these? Then join IMEC, Europe's largest independent research centre in nanotechnology and nanoelectronics.

For our challenges in 3D technology development, we welcome m/f colleagues for these functions

- **Program Manager 3D SoC Design**
- **Manager Back-end-of-line**

Furthermore, we are looking for the following colleagues m/f

- **Product Manager**
- **Research Engineer MPSoC**

Inspired by the idea of a high-tech job at IMEC?
Apply now online at www.imec.be/jobs
or send your CV with a cover letter to
IMEC, Recruitment Team, Kapeldreef 75,
3001 Leuven (Belgium). Any questions?
Contact us by calling +32 16-28.83.64.

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IMEC welcomes each talent - regardless of nationality, age, gender, background, handicap, religion or sexual inclination.

www.imec.be/jobs

Carnegie Mellon®
Call for Faculty

Position available (Security, Privacy, Networking):
The position is based at Carnegie Mellon CyLab Japan in Kobe, Japan. Responsibilities include teaching core technical courses for the Masters of Science in Information Technology - Information Security track (MSIT-IS) program, as well as leading and participating in research projects related to initiatives of Carnegie Mellon CyLab. Candidates must demonstrate strong commitments in teaching, a strong technical background, and a proven research track record evidenced by a publication history in networking, security and/or privacy.

Position available (Networking, Security, Mobility):
The position is based at Carnegie Mellon Silicon Valley campus in Moffett Field, California. Responsibilities include teaching core technical courses for the Information Networking Institute Pittsburgh-Silicon Valley Masters of Science in Information Technology (MSIT) program, as well as leading and participating in research projects related to initiatives of Carnegie Mellon CyLab. Candidates must demonstrate strong commitments in teaching, a strong technical background, and a proven research track record evidenced by a publication history in networking, security and/or mobility.

Please visit **www.ini.cmu.edu** or **www.cylab.cmu.edu** for detailed descriptions and application information.

ini Information Networking Institute
Carnegie Mellon CyLab
Carnegie Mellon ENGINEERING

Full Professor Telecommunication Engineering

The University of Twente invites applicants for a Full Professor Telecommunication Engineering. The successful candidate has demonstrated competence for independent research and leadership of international standing and has a strong commitment to teaching. He/she will establish a comprehensive, advanced research and teaching agenda. Candidates must have excellent management skills and be able to provide leadership at group, faculty and university level. Applicants should have a PhD in a relevant field.

The research area of the group is radio communication with a new focus on short range radio communication and the system aspects in the physical layer of communication systems. Application areas are in-door networks (sensor networks) and e.g. automotive communication systems. Technical solutions can be found in digital signal processing, RF or optical technology. The research challenges are on topics like scalability, dependability, security, (energy) efficiency and low cost achieved by (cross-layer) system optimization. The research of the group is embedded in the CTIT (Centre for Telematics and Information Technology) (http://www.ctit.utwente.nl/), which is the largest academic ICT research institute in the Netherlands. There is an intensive cooperation between the 3 Dutch Technical Universities. Short Range Radio is a research focus of the University of Twente, receiving additional funding.

The group is currently responsible for teaching of 3 undergraduate courses and several graduate courses. The graduate courses will develop according to the new research focus. For more detailed information, please contact the head of the department of EE, Professor dr. ir. J. van Amerongen (e-mail: J.vanAmerongen@utwente.nl), telephone +31 (0)53 489 2791. Information about the group can be found at: http://www.el.utwente.nl/te/

Applicants should address written applications (vacancy number 5012/08/007) preferably by email to the chairman of the selection committee: Prof. dr. ir. A. J. Mouthaan, Dean of the Faculty of Electrical Engineering, Mathematics and Computer Science, P.O Box 217, 7500 AE Enschede, The Netherlands, e-mail: A.J.Mouthaan@ewi.utwente.nl. Applications should be received before 10. April 2008. In several areas women are still under-represented. Therefore we particularly invite women to apply. If you feel qualified, but need to shift your present focus to fit the vacancy and see it as a challenge to be so within a few years, we are happy to discuss with you the option of a 4-year tenure-track position.

University of Twente
The Netherlands

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ieee spectrum classifieds

Ph.D. students wanted in Engineering and Public Policy (EPP): Topics include assessments of: 1) social and economic vulnerabilities of major disruptions in GPS service; 2) use of demand side management to increase power system reliability and assist integration of intermittent renewables; 3) energy saving potential of and RF emissions from efficient DC power supplies; 4) efficient video displays; 5) climate change and water desalinization. Contact Granger Morgan, EPP, Carnegie Mellon. gm5d@andrew.cmu.edu.

Deutsche Telekom Laboratories — Technische Universität Berlin

Deutsche Telekom AG, Europe's leading telecommunications company, is expanding its corporate research and development centre – **Deutsche Telekom Laboratories** – in Germany's vibrant capital Berlin in collaboration with the Technische Universität Berlin.

Deutsche Telekom Laboratories' mission is to explore and develop new information and communication technologies that lay the foundations for Deutsche Telekom's future products and services.

Deutsche Telekom Laboratories comprises a technology-oriented Strategic Research Laboratory and an application-oriented Innovation Development Laboratory.

As a joint venture between a company at the cutting edge of information technology and a leading German research university, Deutsche Telekom Laboratories offers an unprecedented combination of academic freedom, practical focus, and the resources of a major corporation. Deutsche Telekom Laboratories are housed on the main campus of the Technische Universität Berlin with about 30,000 students and several research institutes working in various areas of information and communication technology.

Our Strategic Research Laboratory already includes around 50 senior research scientists and doctoral candidates, and has several openings for highly qualified

Senior Research Scientists

in the broad areas of

- **Security** (network and systems security)
- **Networking** (network architecture, wireless networking, network application, network services)
- **Systems** (virtualization, mobile operating systems)
- **Human Interface** (quality and usability evaluation, interaction design, multimedia interface technologies, multimodal interactive systems)

Successful applicants will have recently completed a doctoral degree, e.g., in computer science, electrical engineering, or other disciplines related to the areas mentioned, and be enthusiastic about the unique opportunity to conduct leading-edge research with immediate impact on the products and services of a major telecoms company.

Applications will be considered until the positions have been filled. Please send your application no later than by March 14, 2008. Outstanding candidates will be invited to give a presentation and have interviews with members of the Recruiting Committee in Berlin. The next symposium is planned for the weekend of March 28-29, 2008. Please consult our web site **www.laboratories.telekom.com** for possible date changes.

Technische Universität Berlin and Deutsche Telekom AG envisage to ensure equal opportunity for men and women, applications from female candidates with the advertised qualifications are explicitly solicited. Provided qualifications are equal, persons with disabilities will be preferred.

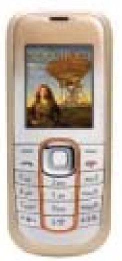
Application materials should include, in a single pdf file in this order, (a) cover letter, (b) one-page statement of research objectives, (c) curriculum vitae, (d) list of publications, and (e) contact information of at least three individuals who may serve as references.

Applications shall be submitted to the attention of Prof. Anja Feldmann or Prof. Sebastian Möller by using the upload function in the **Jobs & Careers** section at **www.laboratories.telekom.com** or by email to

Prof. Anja Feldmann, Ph.D. or Prof. Dr. Sebastian Möller
Deutsche Telekom Laboratories
Email: **laboratories.researchscientist@telekom.de**

the data

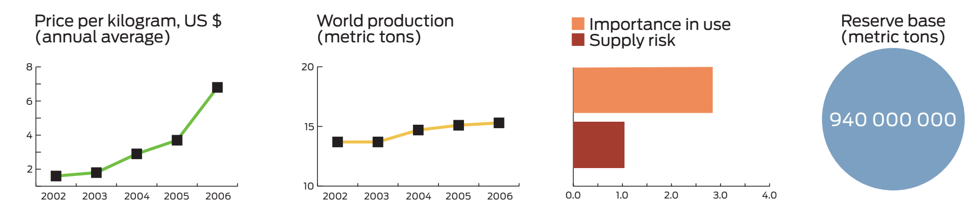
By SAMUEL K. MOORE



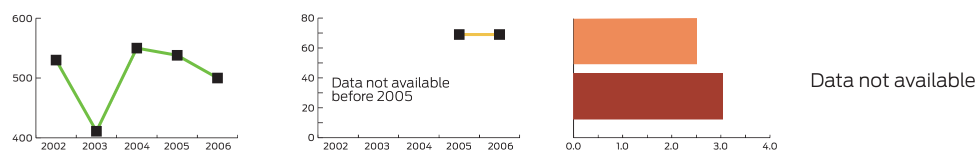
Supply Risk, Scarcity, and Cellphones

YALE UNIVERSITY industrial ecologist Thomas E. Graedel likes to point out in his lectures that when you hold a cellphone, you're holding half the periodic table of elements in your hand. The number of minerals used in electronics has ballooned over the years, and now the industry finds itself highly dependent on some substances whose supply is more precarious than we'd like. Graedel was part of a U.S. government committee that looked at the "criticality"—the combination of importance and supply risk—of a number of key minerals. Some of the most critical are found in cellphones. The ones to worry about, says Graedel, are difficult to find substitutes for and are produced only as by-products of something else, so their own supplies are constrained. Gallium and indium fall into that category. Graedel has also been examining the fact that a more affluent global population may cause even common minerals like copper to become scarce. ❑

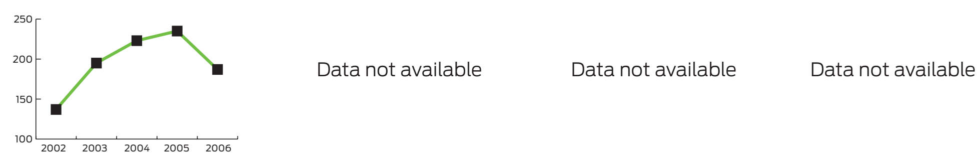
COPPER
Use: Wires, cables, and general infrastructure
Top suppliers: Chile, United States, Indonesia, Peru
Projected scarcity: Copper is extensively mined and has a huge reserve base, but recent analysis has found that for the world population to attain North American affluence by **2100**, more copper would be required than exists in the Earth's crust.



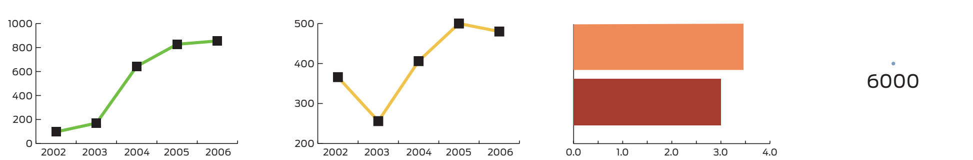
GALLIUM
Use: LEDs, lasers, solar cells, and RF circuits
Top suppliers: China, Germany, Kazakhstan, Japan, Russia
Projected scarcity: Gallium is a by-product of the production of other, more important metals, and so its supply is entirely dependent on the demand for those other metals.



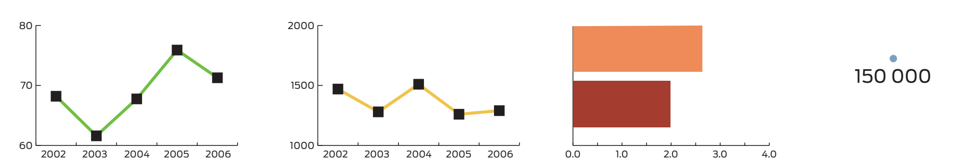
HAFNIUM
Use: Insulator in cutting-edge chips
Top suppliers: Australia, South Africa
Projected scarcity: Even though it is found in the abundant mineral zircon, hafnium is rarely refined, and there is little production data available. Because its use is so new, it's hard to say when it might become scarce.



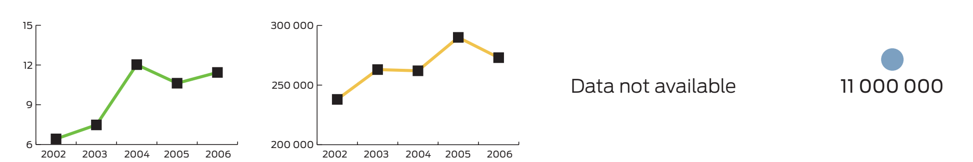
INDIUM
Use: Transparent electrodes that control the pixels in LCD displays
Top suppliers: China, Canada, Japan
Projected scarcity: The price of indium has shot up recently. Unless new resources are found and recycling improves, indium could be scarce by **2020**.



TANTALUM
Use: High-performance capacitors in cellphones and cars
Top suppliers: Australia, Brazil
Projected scarcity: Tantalum will probably not be scarce until after **2030**. But a U.S. government report notes that suppliers can easily hold capacitor makers hostage to price increases.



TIN
Use: Main component of lead-free solder
Top suppliers: China, Indonesia, Peru
Projected scarcity: It's mined extensively and has a huge reserve base, so even if lead solder is eliminated worldwide and the world population's affluence grows, tin will not become scarce.



SOURCES & NOTES: Price, production, and reserve base data are from the U.S. Geological Service's *Mineral Commodity Summaries 2007* and *2006 Mineral Yearbook*. The criticality index is from the U.S. National Research Council's report *Minerals, Critical Minerals, and the U.S. Economy* (November 2007). Analysis of copper and tin are from "Metal Stocks and Sustainability," by R.B. Gordon et al., *Proceedings of the National Academy of Sciences*, 31 January 2006, pp. 1209–1214. Projected scarcity of tantalum and indium were determined by dividing the reserve base by 2006 production. PHOTO: NOKIA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