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SPECIAL REPORT

DREAM JOBS

FOR SOME PEOPLE, ENGINEERING IS A LABOR OF LOVE—FOR WHICH THEY GET PAID. HERE, 10 OF THEM SHARE THEIR STORIES

Jacob Melvin faces his demons at DreamWorks Animation

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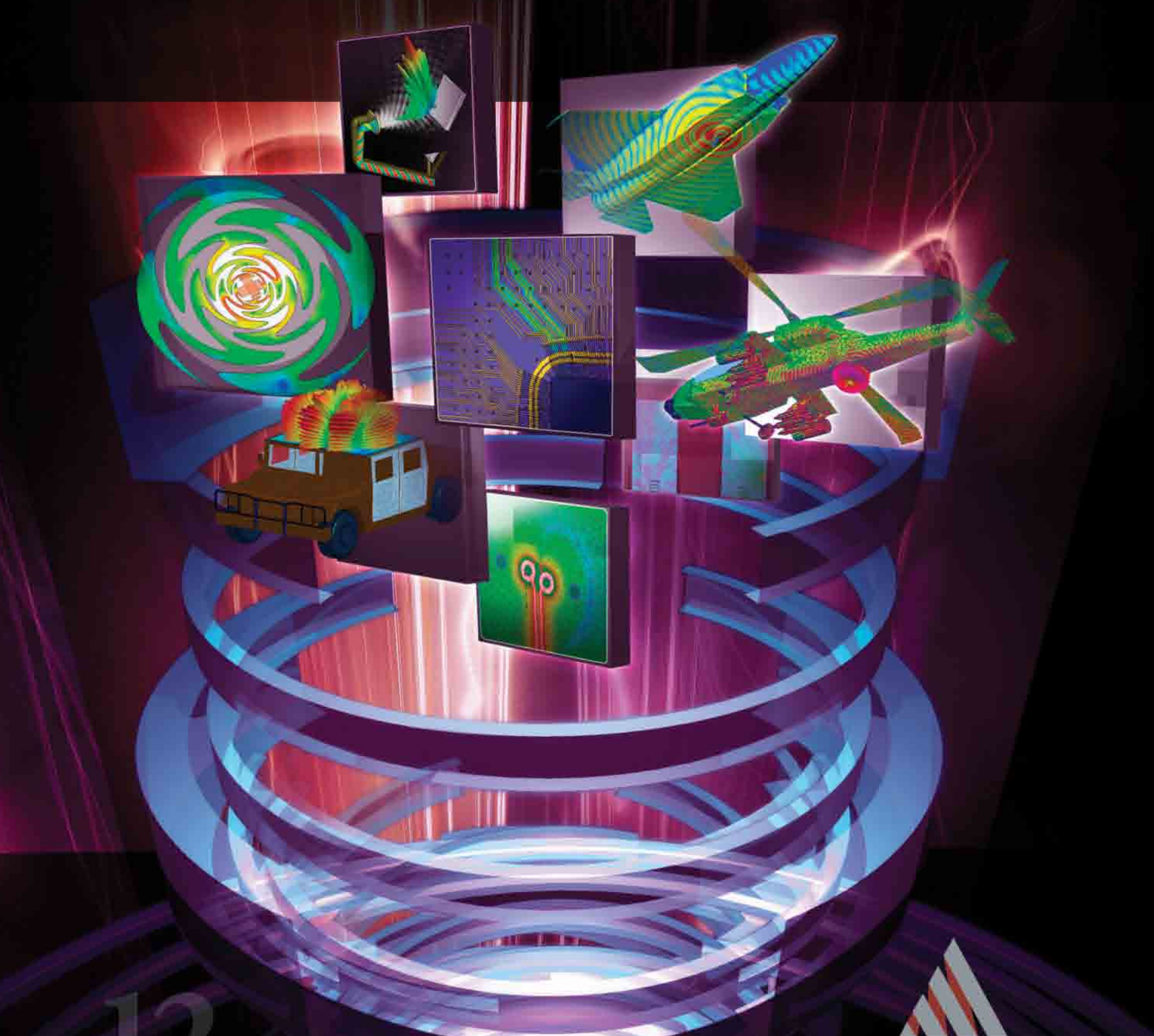

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SPECIAL REPORT

24 DREAM JOBS 2010

A willingness to jump off an obvious career path, make a sudden change in direction, or follow an intriguing idea into the unknown landed these 10 technologists their dream jobs.

DIVER'S FRIEND: Ernst Völlm models his wrist-riding Zurich Scuba Diving Assistant [p. 38].

PHOTO: CÉDRIC WIDMER

COVER: PHOTOS, DREAMWORKS ANIMATION; PHOTO-ILLUSTRATION, STATIK DIGITAL

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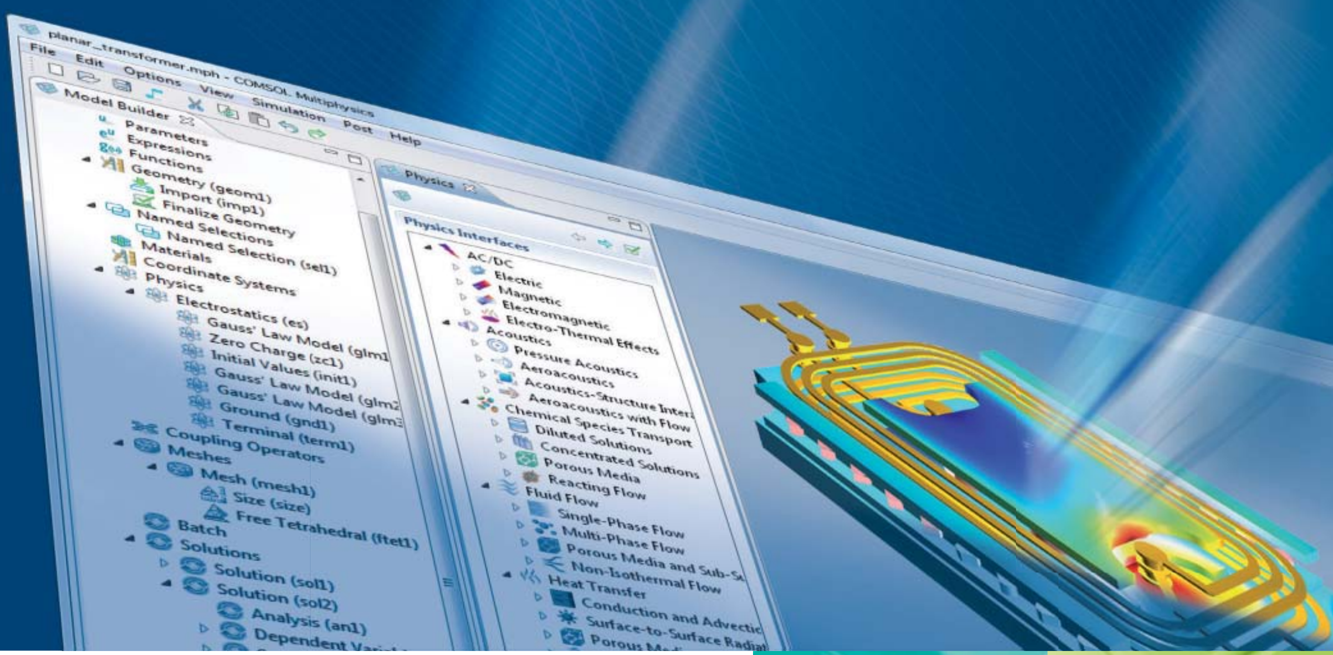

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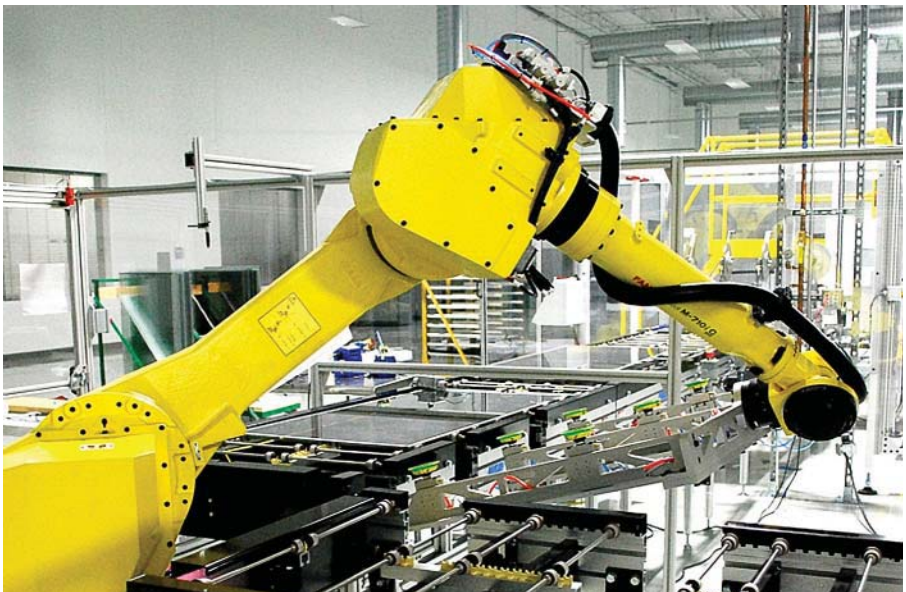

PHOTOS: TOP, HELIOVOLT; BOTTOM, ANNE FADEN/MAX PLANCK INSTITUTE FOR BIOLOGICAL CYBERNETICS

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AVAILABLE 1 FEBRUARY

CAN HELIOVOLT CHALLENGE FIRST SOLAR?

Lately, First Solar has captured most of the headlines in second-generation photovoltaics, with a cadmium telluride thin film that the company says it can make for less than a dollar per watt. Because of its somewhat higher efficiency—and because its variants can be tailored to applications—copper indium gallium selenide (CIGS) is an attractive alternative to CdTe. This is where upstart start-up HelioVolt comes in. Working in collaboration with researchers at the National Renewable Energy Laboratory in Golden, Colo., the company has devised an innovative manufacturing process that it says makes thin-film CIGS PV cells of high quality and efficiency, faster and more economically than competing processes. HelioVolt's Louay Eldada describes the details of the process in an exclusive feature article for *IEEE Spectrum*.

ONLINE FEATURE

GIMME SOME CANDY

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Spectrum's new monthly slideshow, iCandy, shows snapshots of life at its geekiest. The arresting images include a new kind of flight simulator to help pilots train for extreme situations, a drone aircraft that checks for leaky toilets, a solar car in a 3000-kilometer endurance race, a digital tool for foiling forgery, and an iPhone app that lets the user drive a real car from the side of the road.

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FROM ENGINEER TO MANAGER: Do you want to climb the management career ladder but aren't sure what steps to take? Read some of the tips given in the webinar "Geek in the Lead: Growing From Engineer to Manager."

HUMANITARIAN TECHNOLOGY: Representatives from 15 countries, IEEE members, and others have hammered out the basic plans for technologies that will address three challenges. Their work is the result of a workshop held by IEEE and the United Nations Foundation.

PLAGIARISM SCREENING TOOL: The CrossCheck screening tool, which scans article submissions for plagiarism, is now being used by IEEE Manuscript Central, the site where authors submit manuscripts for IEEE society publications.

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back story

Braving the Looky-Loos

CALIFORNIA HAS a reputation for being flaky, and let us reassure you, it's true: Witness the photo shoot that Gregg Segal [above] staged for our Dream Job profile of Brian Gallagher, the guy in charge of electrical systems for the all-electric Aptera car. "The car is very cool—it looks like a spaceship," says Segal. "So we were a real magnet for looky-loos."

Sixty or 70 people stopped to rubberneck. One surfer dude stayed for hours, first hitting on Aptera's public-relations woman, then posing as a PR man himself and inventing answers for onlookers' questions. One woman's car was festooned with bumper stickers in praise of the earth, the trees, and the Wicca religion. Marines from a nearby base trooped by.

Segal began the shoot at a spot overlooking the ocean, not far from Aptera Motors' headquarters, in Carlsbad, Calif. He propped the car up on blocks, up and over the curb, but got in only a few pictures. "Then the park rangers shut us down," he says. He had to finish the shoot with the car parked legally.

Segal, a Californian himself, shoots a lot of cars for advertisements and magazines, but he also pursues conceptual art. "I did a thing on a guy made of garbage," he says. "It's basically a suit made of garbage, put on a manikin. I took him to Japan with me just recently." ❑

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 Technically Speaking column is in *IEEE Spectrum*, Vol. 47, no. 2 (INT), February 2010, p. 23, or in *IEEE Spectrum*, Vol. 47, no. 2 (NA), February 2010, p. 25.

GLENN CHIVENS

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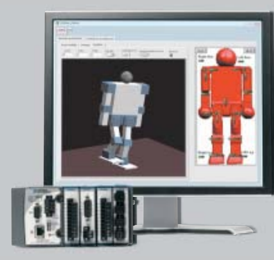

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contributors

GABRIELA HASBUN photographed surgical device designer Catherine Mohr for Dream Jobs [p. 34]. Having had her gall bladder removed with laparoscopic surgery, she found it "twice as interesting" to learn about Mohr's work with robot-assisted surgery. The challenge during the shoot was to keep the machine from overshadowing the person. That's hard to plan beforehand, she says, so she went with a black backdrop and an open mind.

JEN JUDGE photographed electrical engineer and volcano-lightning expert Ron Thomas [p. 28] in "the most remote portrait shoot I've ever done." After riding an hour into New Mexico's El Malpais national monument in Thomas's pickup truck, hiking a few miles to the park's lava tubes, and scrambling down rock faces to find the perfect spot, she wasn't prepared to find her own car locked inside the visitors' parking lot at the end of the day. The state police finally came to her rescue.

JÓZEF LUBACZ, WOJCIECH MAZURCZYK & KRZYSZTOF SZCZYPIORSKI, who wrote "Vice Over IP" [p. 40], are professors at Warsaw University of Technology, in Poland. As part of the Network Security Group at WUT, they have looked since 2002 for new ways to smuggle data through networks, and more important, how to thwart such attempts. In 2008, the group published the first paper about network steganography in IP telephony. After many years spent anticipating evildoers and their machinations, Szczypiorski says his favorite saying comes from Indiana Jones: "Nothing shocks me. I'm a scientist."

EDWARD H. SARGENT decided to study semiconductors that can be applied like paint soon after becoming a professor at the University of Toronto. At the time, many engineers viewed what he was doing as "totally wacky," he recalls. But that research, which he describes in "Connecting the Quantum Dots" [p. 46], allowed him to strike out on his own and make optically interesting semiconductors, without having to depend on an established lab's million-dollar fabrication tools.

GISELLE WEISS is a freelance writer based in Basel, Switzerland. In Dream Jobs, she profiles Ernst Völlm [p. 38], who designs and field-tests advanced dive computers. "I worried that I'd have to go diving in Lake Zurich with Ernst," says Weiss. Happily, she didn't have to. Instead, she drank in the late afternoon sun while Völlm and a buddy dropped their clothes in the parking lot and suited up.

CÉDRIC WIDMER did have to get a little wet while photographing dive computer designer Ernst Völlm. He divided the shoot between Lake Zurich and a local school's swimming pool, where he took his first underwater photographs. After borrowing dive gear from Völlm, he even got a few underwater tips from him. Widmer studied at the Applied Arts School of Vevey, in Switzerland, and has been freelancing since 2005.

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CLOCKWISE FROM TOP LEFT: NICHOLAS TUCKER; JODI HILTON; MITCHELL WEISS; CÉDRIC WIDMER; JEN JUDGE COLLECTION

forum

LETTERS do not represent opinions of IEEE. Short, concise letters are preferred. They may be edited for space and clarity. To post your comments online, go to spectrum.ieee.org. Or write to Forum, *IEEE Spectrum*, 3 Park Ave., 17th Floor, New York, NY 10016-5997, U.S.A.; fax, +1 212 419 7570; e-mail, n.hantman@ieee.org.

Our December 2009 cover feature, "Powerless in Gaza," clearly hit a nerve: The article has generated more letters, e-mails, and comments on our Web site than any other in IEEE Spectrum's *recent history. Below is a sample. You can find more reader correspondence at http://spectrum.ieee.org/gaza. From time to time,* Spectrum *publishes stories about engineers and technologists working in conflict zones and other stressful situations in part to show that no professional works in a vacuum. Whether it's at a company, on a campus, or in government, on a national or international level, they operate in environments infused with politics.*

—Susan Hassler

The Committee for Accuracy in Middle East Reporting in America received numerous complaints about the December issue of *IEEE Spectrum* and its Gaza power station story, mainly from members of IEEE who were dismayed to find a political article about the Middle East in the organization's professional magazine.

On reading the piece by Sharon Weinberger, we, too, found it highly misleading. Primarily, the author has cast the Gazan Palestinians as passive victims of Israel's actions, rather than as key actors bringing hardship upon themselves. Focusing narrowly on the impact of Israel's countermeasures against violence without conveying the magnitude of the provocation is deceptive and explains why so many people knowledgeable about Gaza were troubled by the article.

For nearly a decade, Israel's towns and cities have been targeted by more than 8000 Gazan missiles that have terrorized, maimed, and killed innocent civilians. The Israeli government has pursued many efforts to put a stop to this, including, ultimately, removing every Jewish man, woman, and child (and the dead in their graves) from Gaza. Nevertheless, the violence continued and even intensified, until last winter's war.

The areas of Israel within rocket range of Gaza are a dramatic reflection of adaptive efforts by that nation to protect its citizens. Every school and public facility is reinforced with heavy layers of concrete. Huge concrete slabs overhang many buildings and buffer the doors and windows. In open public areas, bomb shelters are strategically located so that when the rocket siren sounds, everyone can flee in 15 seconds to safety in a shelter.

What is additionally troubling about the article is that key information and context regarding the interruption of diesel fuel supplies to the power plant, which would have underscored the role of Palestinian violence in causing hardship, were omitted. Also unmentioned was the repeated targeting of the crossing points between Israel and Gaza, particularly Nahal Oz, where the fuel storage terminal is located inside Gaza. Numerous Israeli workers and soldiers have been killed and wounded there by Hamas and other groups seeking to shut off deliveries, regardless of the difficulty caused to Palestinians, with the aim of attracting negative publicity for Israel.

Nor did the writer include any hint of the propaganda campaign by Hamas in 2008 when it staged a candlelit parliamentary session in full daylight with the curtains closed—to claim there was no electricity due to Israel's having cut off fuel. In reality, there was no blackout. Israel and Egypt were continuing to supply a full 75 percent of needed electricity, and fuel supplies to Gaza's power plant, while reduced due to rocket fire, were available. Such cynical manipulations are directly related to the difficulties of maintaining the plant in a conflict zone but were omitted by Weinberger.

Palestinian officials at the power plant, whose aims are simply to promote the well-being of their own people, are at the mercy of their own leadership, which frequently exploits the suffering of the Palestinians to garner media attention. At the same time, these officials are virtually certain to be unwilling to speak against the oppressive regime under which they live. *Spectrum* could and should have conveyed this.

Andrea Levin
Executive Director and President
CAMERA
Boston

Sharon Weinberger responds: After receiving no response to my initial e-mail to the Israeli ministry that handles Gaza affairs, I contacted the spokesman again, eventually receiving an acknowledgment. In the meantime I had also contacted a pro-Israeli advocacy group that works with foreign journalists in the hopes they could facilitate contact with the ministry. Despite my repeated requests for an

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update

Wireless Networking Dashes in a New Direction

The Dash7 low-power radio protocol gains momentum

WIRELESS DATA networks are sprouting up like daisies. Wi-Fi hot spots have proliferated. Bluetooth personal-area networks are everywhere. And the push to make electric grids smarter is bringing with it a proliferation of ZigBee radios that use the airwaves to connect electric meters, lamps, light switches, thermostats, and appliances. So it might come as a surprise that yet another wireless-networking scheme, called Dash7, is entering the fray—and appears to be gaining traction. The International Organization for Standardization (ISO) first ratified the standard behind Dash7 in 2004, and it continues to be refined. Like Bluetooth and ZigBee, it's intended for low-power, low-bandwidth digital communications. But Dash7 hardware is designed to use even less power than other schemes, making it especially appropriate for such things as radio-frequency identification (RFID) tags, which must work for years without any external power source.

Whereas the familiar RFID tags used today for such things as door keys are passive devices (they draw their energy from the radio waves their readers emit), Dash7 tags are active, meaning that they make use of small batteries instead. So Dash7 readers don't have to transmit high RF power levels and consequently can be manufactured inexpensively—yet they can communicate with tags located hundreds of meters away or even farther when conditions are right.

Dash7 operates at around 433 megahertz, a globally available frequency also used, for example, in many keyless entry systems for automobiles. The corresponding wavelength is about 70 centimeters, which makes it difficult to design efficient antennas that are conveniently compact. Dash7 supporters say that the advantage of using a

MANIFEST DESTINY: At one time, cargo lists existed only on paper. Now these records are not only electronic, they can reside on radio-frequency identification tags attached to the cargo itself. Dash7-based RFID tags, like the one shown here, have been helping to address the military's many logistical challenges. They may soon become popular in the commercial sector.
PHOTO: SAVI TECHNOLOGY

768 Number of bits in the RSA encryption code recently cracked by scientists from Europe and Japan. The attack required the equivalent of 2000 CPU cores working for a full year to find the prime factors of a large number. The scientists say that today's 1024-bit codes could be vulnerable within the decade.

update

wavelength this long is that it can penetrate such obstacles as concrete walls and work in environments with large amounts of metallic clutter. This, the Dash7 advocates contend, is more of a problem for ZigBee, which employs 868 MHz, 915 MHz, or most popularly, 2.4 gigahertz, the last of which is also used for many Wi-Fi networks. Using "2.4 GHz is really nasty in environments with a lot of metal," says Pat Burns, vice president of marketing and licensing for Savi Technology, the Mountain View, Calif., company that first devised the Dash7 technology.

Jon Adams, Freescale Semiconductor's director of business development for wireless connectivity operations and a former vice chairman of the ZigBee Alliance, is, however, skeptical. "Wavelength is only part of the equation," he says, adding that if the only way for a radio signal to pass into or out of a room is through a window, a shorter wavelength may, in fact, work better. "I think some of what we're hearing about Dash7 is market positioning," he says.

The search for a market for Dash7 isn't new. Savi began developing this technology two decades ago, intending it initially as a way for parents to keep track of their kids during family outings. But that application proved a dud. According to Burns, advisors told Savi's founders, recent graduates of Stanford, "You guys have to do a reboot and find a different business model." So they shifted plans, and following the first Gulf War, they began selling active RFID tags to the U.S. Department of Defense for tracking shipments of war materials.

The U.S. military embraced this radio tagging system and has been employing it increasingly. This, of course, has been a boon for Savi. But in 2006, the Defense Department pressured Savi to license its patents to several other companies so that the military wouldn't be dependent on a single supplier. In January of 2009, the DOD awarded a US $428 million contract for Dash7 RFID devices, software, and services to four companies: Savi, Northrop Grumman, Systems & Process Engineering Corp., and Unisys.

In a move to expand its reach into the commercial sector, Savi joined with other companies to form the Dash7 Alliance this past March. Savi also liberalized its licensing arrangements in October, removing up-front fees and reducing royalties to as little as 5 cents per tag, which, according to Burns, has made dozens of companies eager to use Dash7 in their equipment.

One is RFind Systems, of Kelowna, B.C., Canada, which began more than four years ago to develop RFID tags that broadcast their positions whenever they are moved. Customers might use this system to locate pallets within a factory or cars on a dealer's lot, for example.

According to Sharon Barnes, RFind's chief executive officer, the company's original tags employed a proprietary protocol to communicate with one another and to determine their location with respect to a small set of fixed tags. Now RFind is adopting Dash7 to do the same.

The new technology has clearly helped this company refine its product line, but Dash7's general claims for far less power use than ZigBee depend on the details of how the particular wireless network is set up. And its promise of better range, too, hinges on the environment in which it is used. But one uncontested attribute of Dash7 is that its name has a clear and sensible derivation: It's a catchy contraction for ISO 18000-7. That's something that neither Wi-Fi, nor Bluetooth, nor ZigBee can boast.

—David Schneider

PHILLIP GENTRY/THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

A Critical Perspective on Climategate

The disclosure of e-mails and other documents by scientists at the University of East Anglia, in England, has aroused wide consternation. The University of Alabama's John R. Christy [above], an atmospheric scientist who has taken a contrarian view of the world's recent temperature history, comments on the significance of the British work and the implications of the climate scandal. See http://spectrum.ieee.org/energy/policy/critical-perspective-on-climategate.

36 TESLA New world record for a "resistive" class of magnet. In December, the National High Magnetic Field Laboratory at Florida State University bested by 1 tesla its own previous record, which was jointly held with France's Grenoble High Magnetic Field Laboratory.

BRITISH SPACE POWER: Astronaut Tim Peak will be in Her Majesty's space agency now.
PHOTO: ALEX RUMFORD

UK Gets a Space Agency of Its Very Own

Budget, research strategy, and much else have yet to be worked out

IT'S A little surprising that the land of Sir Isaac Newton does not have its own space agency. An attempt to fill that void came with the announcement in December that the UK would create a "bureaucracy busting" organization to oversee British civilian space and satellite activities.

Now comes the hard part. The announcement did not specify who will lead the new agency, how much funding it will receive, how those funds will be distributed and to what projects, or where the agency will be based, among other things. "All that has happened is that a decision has been taken to set up a space agency," says Richard Peckham, business development director for space systems company EADS Astrium and chairman of UKspace, a space industry trade association. At press time, a government working group was being set up to sort out the many details.

Until it does, space activities will continue to be coordinated through a small office called the British National Space Centre. Unlike the new agency, the BNSC doesn't have its own funds to distribute or its own research agenda. The money instead comes from 10 government entities; the BNSC's role is to establish which department or research council or office will pay for what. If the program crosses disciplines or applications—as the European Union's Galileo global navigation system does—that process can quickly bog down.

"BNSC is almost like a beggar with a hat," says Peckham. "They spend a lot of time trying to stitch together funding, sometimes without success, and we end up not joining an important program simply because departments won't fund it." As a result, he says, the UK rarely takes the lead in proposing new efforts. "There's no continuity, no real strategic approach to space," he says. "It's very ad hoc." The British government spent about £230 million (US $370 million) last year on civilian space programs, about 90 percent of which gets funneled into the European Space Agency.

The idea of creating an independent space agency first emerged in the 1980s, says Rob Coppinger, a writer and blogger for the aerospace publisher Flight. "We got the BNSC instead," he says. The idea was resurrected three years ago during a national review of space policy, and momentum began building last July, when ESA announced it would set up its first UK-based research center in Oxfordshire.

Experts hope the new agency will lift Britain's standing among space-faring nations. The December announcement was "widely welcomed by the whole UK space community," says Richard Holdaway, director of space science and technology at the Rutherford Appleton Laboratory, where the new ESA space center is based. The country already has world-leading expertise in space-based instrumentation and microsatellite technology, he notes, as well as a robust space industry that generates about £6.5 billion of revenue and employs some 68 000 people.

"There are huge economic and educational benefits to having a space program," Holdaway says. "The general sentiment is that now is the time to set up a space agency." —JEAN KUMAGAI

news briefs

Mirror, Mirror... Cryogenic testing began in January for the first 6 of 18 mirrors to be used in the James Webb Space Telescope, Hubble's successor. The 6.5-meter beryllium mirrors weigh just 21 kilograms each. Testing should conclude in 2011, and a launch of the telescope is planned for 2014.
PHOTO: EMMETT GIVENS/MSFC/NASA

15 PERCENT Fraction of solar systems in the Milky Way galaxy that resemble our own, according to new research by astronomers at Ohio State University.

update

A Compass in Every Smartphone

Cheaper, better electronic compasses bring augmented reality and other features to your handset

WHICH WAY? The Storm, the iPhone, and the Pre all have compasses.
PHOTOS: FROM LEFT, RESEARCH IN MOTION; APPLE; PALM

AN OLD axiom says that in order to know where you're going, you first have to know where you are. To that, add that you should know which way you're facing. Makers of wireless handsets, having already installed GPS receivers, are poised to flood the market with phones containing tiny electronic compasses that allow the gadget to sense exactly what direction it's facing.

According to electronics industry analysis firm iSuppli Corp., in El Segundo, Calif., we can expect to see an increasing number of cellphones containing electronic compasses. Analysts predict the market for magnetic compass sensors will grow from the 8.7 million manufactured in 2008 to more than 540 million in 2013.

Underlying the jump is a combination of consumer demand for the whiz-bang feature of the moment and a steep drop in price fueled by manufacturing process improvements.

"Navigation is emerging as a must-have feature in smartphones," says Richard Dixon, a senior analyst at iSuppli. Consumers are already looking to their phones for turn-by-turn directions. With the addition of compasses, the beginnings of location-based augmented reality are also emerging, wherein a street map or even the phone's camera image could be overlaid with highly detailed information about what's in front of you.

The component that handset makers are exploiting to make these feats possible is the three-axis magnetometer. The sensor system's job is to home in on Earth's magnetic field and use that as a reference for determining the handset's orientation along the *x*-, *y*-, and *z*-axes. Three axes are important "because that third sensor allows the handheld device to correct for the orientation of Earth's magnetic field at a given location, as well as the relative position of the device," says Mark Laich, vice president of worldwide sales at Memsic, a maker of electronic compasses based in Andover, Mass. "Otherwise users would have to hold the phone precisely parallel to the ground or in some other position that may not correspond to how they normally use it."

Like the rest of the electronics industry, electronic compass makers have been making their products smaller, cheaper, and more energy efficient. And they reached a watershed moment in 2009, when the price of three-axis magnetometers dipped below US $1 per device. "Six months ago, magnetic sensors were selling at $1.50 each, but the price is coming down rapidly," says Laich. "They're now at the sub-$0.50 point and look to get even cheaper as production volumes increase."

Memsic and other new entrants into the magnetometer market for mobile devices mostly sell sensors that take advantage of amorphous magnetic alloys whose resistances change when acted upon by the planet's magnetic field. Memsic, for example, uses three chips, each containing a thin film of the alloy. The chips, which are set at right angles to each other, are incorporated into a Wheatstone bridge circuit so that when you move the phone, the change in resistance resulting from the perceived change in the strength or direction of the magnetic field is output as a change in voltage.

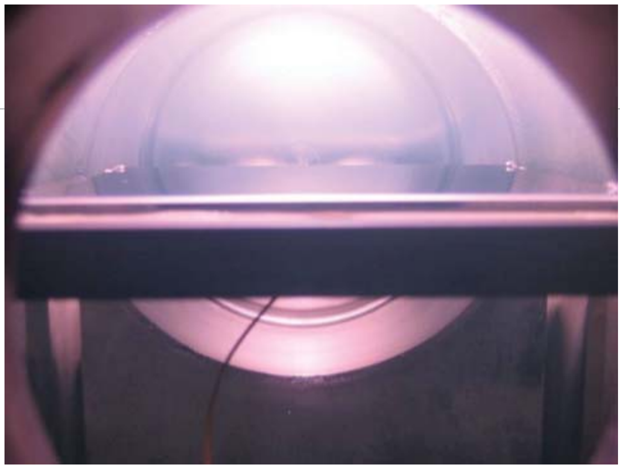
Aichi Steel, Honeywell, Memsic, and Sensitec have all developed magnetoresistive sensors in an effort to take a bite out of AKM Semiconductor's 95 percent share of the mobile phone compass market. AKM, in San Jose, Calif., uses a technology that relies on the Hall effect, in which electrons racing through a conductor in the presence of a magnetic field are forced to one edge of the conductor, creating a voltage difference whose orientation is perpendicular to the magnetic field.

AKM's competitors claim their devices are power misers compared with Hall effect sensors, a really big deal in palm-size devices that barely have room for the batteries they stow. The companies also say that their sensors are more sensitive and have quicker response times.

Naturally, AKM disagrees with its competitors' assessment. "We make magnetoresistive components but don't think they're a good solution for cellphones," says Richard Kulavik, application engineering manager at AKM. "One good reason is that the steady-state current of one of our Hall effect sensors may be higher, but magnetoresistive sensors—in an object like a cellphone that is filled with metal and is constantly giving off pulses of current—take on their own magnetic signatures and have to be continually degaussed. And degaussing takes a huge amount of current."

Nevertheless, the competition is making important inroads. Geneva-based STMicroelectronics, a leading accelerometer maker, chose Honeywell's magnetoresistive technology over Hall sensors to make the first single-package combination accelerometer-magnetometer on the market. One reason ST cited was that Honeywell's device provides the same sensitivity in all three axes without the need for the magnetic flux concentrators that Hall effect sensors require. And as for the degaussing issue, ST found it required only a matter of microamperes.

—Willie D. Jones



GOBBLE, GOBBLE: PACMAN munches nanoparticles on an EUV mask.

PHOTO: URBANA-CHAMPAIGN CENTER FOR PLASMA-MATERIAL INTERACTIONS

"Pac-Man" Process Eats Nanodirt

Cleaning up nanoparticles is critical to commercializing extreme UV lithography

One of the problems faced by developers of next-generation lithography tools is the debris that accumulates inside the delicate tools and interferes with wafer throughput. But now a team of researchers at the University of Illinois at Urbana-Champaign has come up with a way of gobbling up these vexing contaminants.

Extreme ultraviolet lithography (EUVL), which bounces 13.5-nanometer light off a mask containing the chip pattern and onto the silicon wafer, is the method of choice to make chips due out between 2015 and 2022. EUVL tools were supposed to be ready a few years ago, but technical problems, including debris, prevented commercialization. So far, toolmakers have focused on shielding the machinery from the debris generated during the process of creating EUV photons.

But light-source debris isn't the only kind of contamination. A lesser-known but equally vexing problem is the much smaller kind of gunk that collects inside the vacuum-sealed machines as a side effect of the lithography process itself. Carbon particles and nanoparticles are always present on masks, but the particles' size, tolerable on today's masks, becomes a problem when the features shrink below 16 nm. Martin J. Neumann, acting director at Urbana-Champaign's Center for Plasma-Material Interactions, graduate student Wayne Lytle, and plasma physicist David Ruzic developed a system to clean things up.

Roughly 30 to 200 nm in size, nanoparticles cling to the surfaces of masks like lint, causing defects, distortions, and other problems in the projected pattern. Lithography toolmaker ASML has invested "years and substantive R&D budget" to prevent particle buildup, using a combination of nested mask pods, automation, and other tricks.

But completely preventing their accumulation is impossible, short of redesigning the entire fabrication process, says Neumann. "Even the cleanest room will have nanoparticles." EUVL tools are vacuum-sealed, but they must still collect masks from external compartments exposed to the clean-room air. Multiple masks are used to expose the same wafer and are changed out using a jukeboxlike robot. Every time the robot handles the masks, taking them in and out of an external chamber, says Neumann, they are "just absolutely covered in debris."

The cleaning system developed by the Illinois researchers is called PACMAN (Plasma Assisted Cleaning by Helium Metastable Atom Neutralization). Like the cheery yellow 1980s game character, PACMAN literally eats the nanopellets.

The process has two steps. For particles on the order of 20 nm, a pulsed electric field in conjunction with a helium plasma confers a static charge on the nanoparticles, which are then repelled from the surface of silicon. But the remaining nanoparticles are too big for such treatment. These are vanquished by the plasma's cargo of metastable helium atoms (which are roughly halfway between ground state and excited ionized state). Because of its peculiar energy state, the helium can break up the particles and free them from the surface.

—Sally Adee

2 MINUTES Approximately how much time a person needs to be in flight to get the same dosage of radiation as that produced by the new body scanners being installed in U.S. airports.

update

Wireless Sensors That Live Forever

Energy harvesters and radioisotopes fuel tiny transmitters

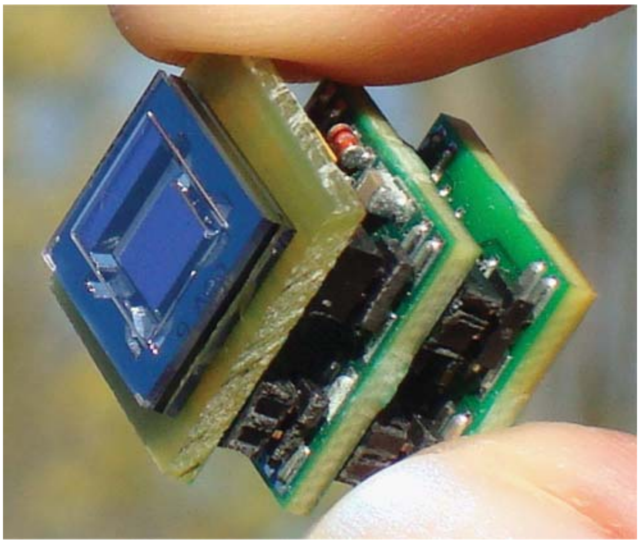
SOON ENOUGH, say some engineers, miniature wireless sensors will be located in spots where it would be inconvenient, to say the least, to change their batteries—inside your body, within the steel and concrete of buildings, in the dangerous innards of chemical plants. But today, even the most robust nodes can be counted on to last only a few years. Ideally, engineers need a sensor that can last forever without external power sources or battery changes. According to research presented in December at the International Electron Devices Meeting, in Baltimore, that dream is within reach.

Two research teams tackled the problem of sensor longevity in two very different ways. Both methods rely on piezoelectric power generation, in which a microelectromechanical systems (MEMS) cantilever converts mechanical motions into electrical power. However, the cantilever's movements are propelled by very different mechanisms—one by a radioisotope and the other by vibrations harvested from the environment. In a big step forward, both methods fully powered autonomous wireless systems.

All self-powered communication nodes must be able to retain their memory state and periodically transmit that state. These tasks require an average power budget of between about 0.1 microwatt and 1 milliwatt, a budget that can be met by either of the two methods of power generation, as the recent research showed.

Cornell University researchers Amit Lal and Steven Tin created a piezoelectric generator using a small amount of nickel-63 (Ni-63)—a mildly radioactive isotope with a few extra neutrons in its nucleus. When it decays, Ni-63 emits relatively harmless beta particles (energetic electrons that penetrate only about 21 micrometers into a surface). The device was able to create sufficient output energy to achieve a 5-mW RF pulse every three minutes. Most important, because the half-life of Ni-63 is just over 100 years, the device could function autonomously, according to Lal and Tin, for about that long.

At the Holst Centre, part of nanoelectronics research center Imec, in the Netherlands, Rene Elfrink, a research engineer, and his colleagues took a different approach, creating a wireless, autonomous temperature sensor powered by an aluminum nitride vibration harvester.



FOREVER NODE: Imec created this energy-harvesting wireless sensor.
PHOTO: IMEC

Vibration energy harvesting typically requires a small (approximately 1 μm) vibration at a specific frequency. Powered by the harvester, the device measured the temperature and transmitted the data to a base station up to 15 meters away every 15 seconds.

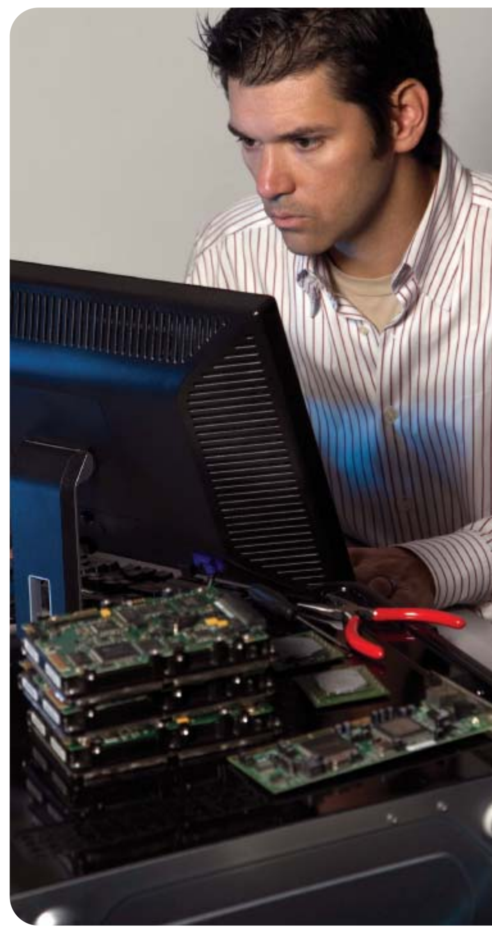
Existing energy harvesters tend to be fine machined, a costly method that can produce devices that generate power at levels from microwatts to watts. Such large, fine-machined devices can generate more power than smaller, MEMS devices like Imec's. But MEMS devices are cheaper to produce, easier to integrate with existing sensors, and now they can generate enough power to run a wireless sensor node.

Unpackaged, the Imec device produced 85 μW, a record-setting amount for a MEMS harvester. However, when packaged at atmospheric pressure (as most devices are), air damping caused the output to fall below 10 μW—not enough to keep the sensor transmitting data every 15 seconds. Elfrink's team solved the problem with a vacuum package.

Peter Hartwell, a senior researcher at HP Labs, in Palo Alto, Calif., says Imec's technology is "definitely a step forward." Energy harvesting research is important to HP Labs, which is developing sensors for its Central Nervous System for the Earth project, a vision of peppering the world with minuscule sensors. Power is one of the remaining obstacles in making the vision a reality; HP Labs' accelerometers require about 50 mW.

However, says Hartwell, vibration harvesters so far are tuned too narrowly to specific frequencies to be useful everywhere.

—SALLY ADEE



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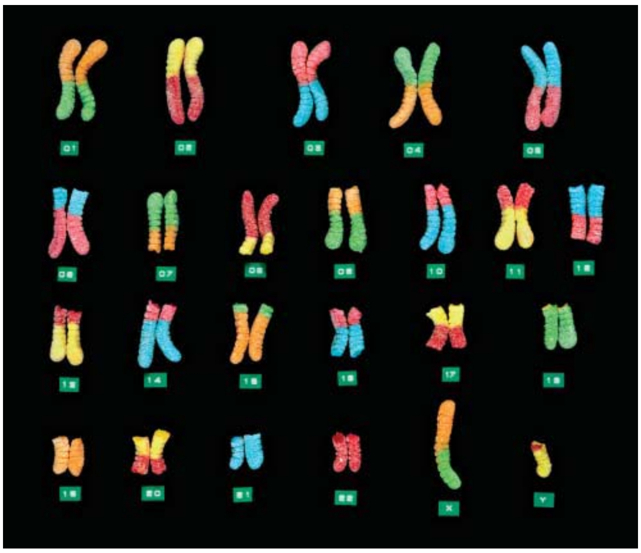
the big picture

SLING BLADE
Neighbors commonly compete over who has the greenest, most manicured lawn. But for Don Wales, the driver who intends to break the current lawn-mower land-speed record of 130 kilometers per hour (80.8 miles per hour) this month, he who cuts fastest wins. Wales's machine, dubbed Project Runningblade, will make the high-speed dash on sand but must then prove capable of actually cutting grass. For the past three years, a team of automotive engineers has been fine-tuning the mower's power train so it can deliver the burst of speed needed to cover the 1-mile course in less than 36 seconds. They're also honing its aerodynamics so the mower won't become airborne at top speed.

PHOTO: PRESS ASSOCIATION/AP IMAGES

geek life



THE $100 GENOME

In a few years, millions will have purchased their own genomes—and perhaps those of others

FOR THE price of a sports car, you can have a pint of your blood drawn and a month later receive your entire genome—all 6 billion base pairs—encoded in a 1.5-gigabyte data file. That means the price has dropped to 1/50 000 of what it was less than a decade ago (the first genome, after all, cost US $3 billion). Yet the price is expected to fall to 1/1000 of the current price in the next four years.

The cultural ramifications of a $100 genome—which is where we're headed, whether it takes 4 years or 10—are as wide and deep as those of any other recent innovation, including search engines and cellphones.

"Personal genomics goes far beyond medicine," says George Church, a professor of genetics at Harvard Medical School and the founder of the open-access Personal Genome Project. "What if you could test everything in the air around you? You could say, 'I don't want to go into that room because it's full of swine flu.' " Church suggests that refrigerator-size vending machines offering rapid genetic testing of biosamples may one day be as common as Internet kiosks. Imagine being able to easily and cheaply find out every genetic pitfall and bragging point about a potential mate right in the middle of your first date.

Of course, genetic sequencing today is neither fully automated nor cheap enough to be delivered by vending machine. But the price is dropping faster than that of transistors in the glory days of Moore's Law.

Today, Knome, in Cambridge, Mass., will sequence your entire genome for $68 500. Illumina, based in San Diego, goes one better—it charges only $48 000 and delivers the data on a new MacBook or iMac that you get to keep. Jay Flatley, Illumina's president and CEO, says that within two years a personal genome will cost between $5000 and $10 000 and that within five years "we'll be pressing up against $1000." As of last September, Illumina had sequenced 28 complete human genomes. "Next year," Flatley says, "there will be thousands."

One company is already charging a mere $5000 per genome—in bulk orders of a thousand or more. Complete Genomics of Mountain View, Calif., which styles itself as a research genomics institution only, doesn't offer a single-genome price.

Nevertheless, CEO Clifford Reid says he sees a consumer genomics marketplace springing up out of nowhere—like that for personal computers in the 1980s. "Right now it's a purchase for wealthy individuals, because the price is so high and the medically actionable information that you learn from your genome is so low." But, Reid says, "it's inevitable that this is going to be a very large market. The only question is how long it will take the prices to come down and for the discoveries to go up." [See The Data, on the last page of this issue, for more market trends.]

Church agrees that early adopters are helping to underwrite the fledgling personal genomics industry. "The people who bought cellphones the size of their heads—the rest of the world is benefitting from the fact that they fueled that embryonic industry at a time when it needed money," Church said. "The same is true for personal genomics. The people who are willing to do the early adoption today will be paying for the privilege of being guinea pigs."

Church's Personal Genome Project seeks to cut price out of the equation entirely, underwriting the sequencing of genomes of people whose histories, conditions, or medical records it considers interesting for research purposes—making their genomes and medical records, he warns, publicly available. "We are not publishing our volunteers' names," Church said. "But we tell them to think about it as if we were. We're making enough information about them available that, if somebody worked at it, they could figure out the name." He says that 15 000 people have volunteered for the project already.

One person who would, nonetheless, like to participate is Laura White, a lead analyst at life sciences advisory firm TSG Partners, in Atlanta. She hasn't yet heard whether she's been accepted as a volunteer. "For me, it's fascinating, which is why I signed up," she said. "I could end up finding out I have something I'm not comfortable with at all. But given the option, I want to know." —MARK ANDERSON

KEVIN VAN AELST

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Carebots

A scientist creates robots that help children

LAST OCTOBER, Maja Matarić learned a new twist on an old saying: Never share the stage with kids, animals—or robots.

She presented Bandit, a caregiving robot, to an audience of Los Angeles health-care workers, showing them videos of it blowing bubbles, making sounds, and mimicking the movements of children with autism and related disorders, winning over the kids better than most human caregivers would have done.

But when Matarić opened the floor to the audience, the first question wasn't about how robotic caretakers might help people with cognitive and physical disabilities. Instead, a voice shouted from the back, "Can we come up and meet Bandit?"

Matarić, a University of Southern California professor in the computer science department and neuroscience program, has been studying the use of robots in health care since her graduate school days at MIT. Matarić envisions using therapeutic robots to rehabilitate patients who've had strokes or trauma injuries and to take care of the elderly, in addition to treating autism.

She already uses the robots to study patients. Bandit, for example, quietly collects data on a child's behavior so that it can be used to predict, for instance, when the child is about to stop exercising. Matarić's team hopes to try this out on children and young adults with autism, including a high-functioning form known as Asperger's syndrome.

Some psychologists have speculated that Newton—and Edison, Einstein, and Tesla, to name just three others—had Asperger's. True or not, such titans were able to rely exclusively on their superior intellects. For everyone else, social skills are essential.

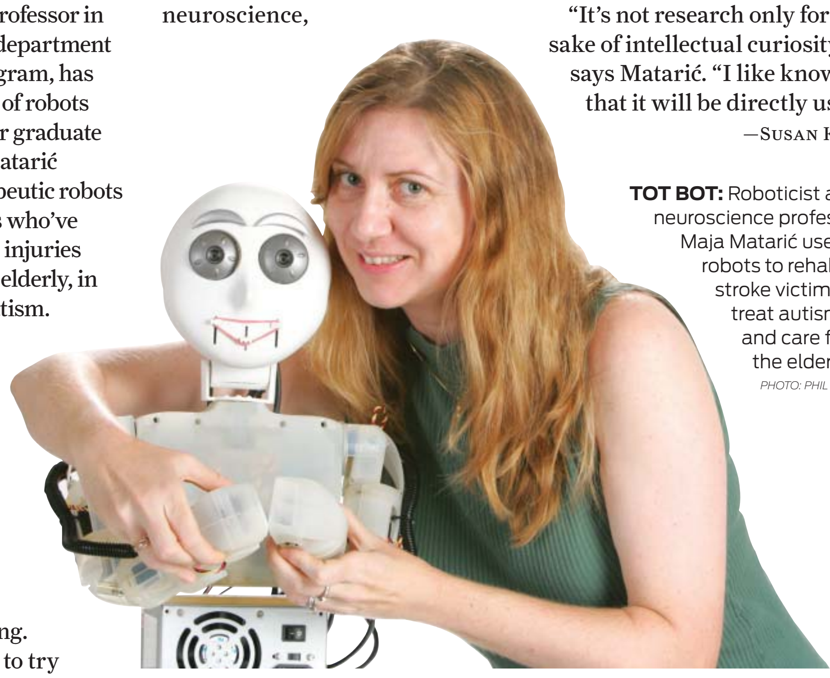
"It's an exciting new area," Matarić says. "But it's also frustrating, because it's still so novel that it's difficult to get funding for large-scale clinical trials." In 2002, she founded the USC Center for Robotics and Embedded Systems to foster collaborations among experts in engineering, computer science, neuroscience, cognitive science, social science, and education.

Interdisciplinary work comes naturally to Matarić. When she moved to the United States from her native Yugoslavia at age 16, she was interested in art and psychology. But an uncle who worked as an aerospace engineer guided her to the more employable area of computer science. "Those interests all came together in artificial intelligence," she says.

She earned a bachelor's in computer science from the University of Kansas in 1987, then enrolled at MIT, earning a master's in 1990 and a Ph.D. in 1994. She taught computer science at Brandeis University, in Waltham, Mass., before joining the faculty of USC in 1997, becoming a full professor three years ago. Along the way, Matarić wrote the popular introductory robotics textbook *The Robotics Primer* (MIT Press, 2007). She's an IEEE Senior Member and an AAAS Fellow.

"It's not research only for the sake of intellectual curiosity," says Matarić. "I like knowing that it will be directly useful."

—SUSAN KARLIN



TOT BOT: Roboticist and neuroscience professor Maja Matarić uses robots to rehabilitate stroke victims, treat autism, and care for the elderly.

PHOTO: PHIL CHANNING

geek life

ISTOCKPHOTO

Smokes and Mirrors

Can a virtual-reality program help smokers kick the habit? Researchers at the Université du Québec en Outaouais, in Gatineau, split 91 smokers into two groups: one that crushed virtual cigarettes and a control group that grabbed floating balls. After three months of gaming and minimal therapy, 15 percent of the crushers and 2 percent of the controls stopped smoking; six months later, there were twice as many crushers compared to controls. Of course, now the crushers have to be weaned from the video game.

—Susan Karlin

hands on

MICRO DRONE: Adding a video camera and radio downlink to a radio-controlled model airplane has become easy.
PHOTO: DAVID SCHNEIDER

DIY EYE IN THE SKY

How to get a pilot's-eye view while keeping both feet on the ground

LIKE A lot of people, I love flying. The few times I've taken flying lessons, though, I've quickly given up. For one thing, they're expensive, and I'm a cheapskate. Also, flying small planes is, well, dangerous. Even a couple of minor incidents where the instructor was taken by surprise were enough to give me cold feet. Clearly, I must lack something in the right-stuff department.

Fortunately, technology has caught up with my longings to soar. In the latest twist on a hobby I've enjoyed for years—flying radio-controlled models—the pilot need no longer view the world from the ground. Now you can easily outfit a model with a video camera and a radio downlink, allowing you to take in the experience from the point of view of the cockpit. It's sort of like having your own private MQ-1 Predator—minus the Hellfire missiles.

This new branch of the hobby goes by the name first-person view, or FPV for short. FPV flying has been controversial in modeling circles because some of the people doing it fly very high and well out of sight, meaning that their models might crash someplace where they could do some damage.

It was only a year or so ago that the Academy of Model Aeronautics, an organization that provides U.S. modelers with liability insurance, deemed FPV flying an acceptable activity at its chartered airfields—and only if two pilots work in tandem. One looks up at the plane in the usual manner while the other does the FPV flying. Their radio-control transmitters need to be linked so that the person looking at the plane can take control in an instant if the FPV pilot loses orientation or flies too far away. Done in this way, FPV is no more dangerous than flying radio-controlled models in the standard fashion.

While it's hard to suppress the urge to take off on a cross-country jaunt when flying an FPV model, with a little self-control you can responsibly stay in visual range and still have a great deal of fun. And this way you're far less likely to lose your plane.

Having read up about this activity at such sites at DIYDrones.com and FPVPilot.com, I was eager to give it a try. I purchased a tiny SN555 video camera for US $129 from Hobby Wireless, an online seller of FPV gear. While there, for another $95 I also bought a diminutive 0.5-watt video transmitter and a matching receiver tuned to 910 megahertz, which is well separated from the frequencies used for radio-controlled model aircraft in the United States (72 MHz and 2.4 gigahertz). Note, though, that you need an FCC amateur license to operate a 910-MHz transmitter in the United States.

The big question was what model to use. I ended up with a plane called the Twin Star II, which is manufactured by Multiplex Modellsport of Bretten-Gölshausen, Germany. It normally retails for $150, but I picked up a kit for this model at the bargain price of $86 from BP Hobbies of Piscataway, N.J.

The Twin Star works well for FPV because it is electrically powered, so there's no oily engine exhaust to foul the camera lens. And as the name implies, it has two motors mounted on the wings, rather than a single motor up front. So there's no spinning prop to obscure the view from the cockpit.

This model, made entirely of high-strength foam, is very easy to put together. But

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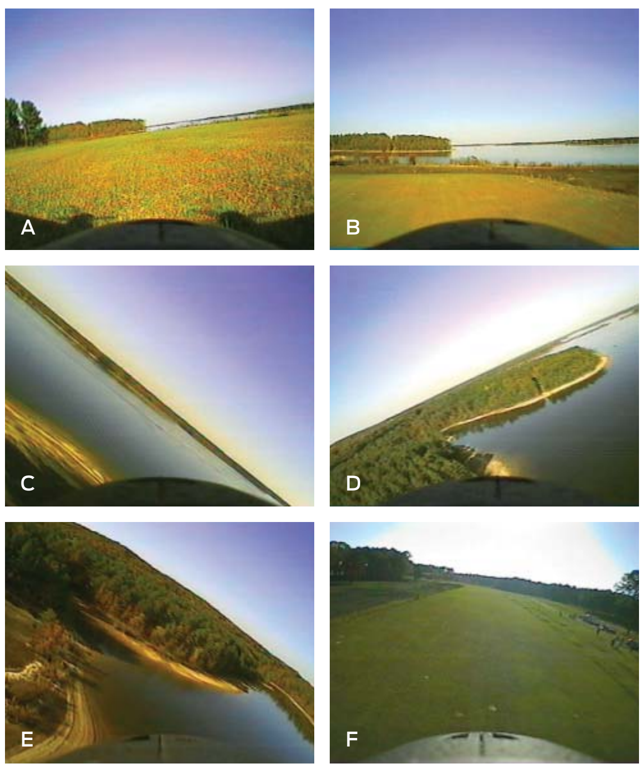
because it wasn't designed for FPV flying, I made several modifications. For example, the Twin Star comes with no landing gear at all; I added one. And although the kit includes two brushed electric motors, the plane really needs more oomph to carry the extra payload of electronic equipment, modest though it is. So I installed beefy brushless motors (BP U2212-13s, $24 each from BP Hobbies) and 30-ampere electronic speed controllers (made by Exceed-RC, $18 each from XHeli.com).

Before joining the fuselage halves, I cut an extra opening on the bottom to provide access to additional space for the electronics. I'm glad I did that because there was a lot to stuff in. Whereas a typical model of this sort carries a single battery pack, mine uses three: one for the two motors, one for the video camera and transmitter, and one for the radio-control receiver and the four servomechanisms that operate the flight-control surfaces. I also installed a fifth servo up front, which allows me to pan the camera to the left and right while flying.

One of the biggest challenges was keeping electrical noise down to a dull roar. For example, I had initially planned to use a DC-to-DC converter to run the plane's radio-control receiver and servos, but the one I bought generated a lot of radio-frequency noise. I ended up using a battery, which added 85 grams (3 ounces) to an already heavy build. Fortunately, the Twin Star has a good wing size, so it still floats well, and its two brushless motors can generate more than 250 W (about one-third of a horsepower), so there's plenty of thrust to get everything off the ground.



FLIGHT SIGHTS: Selected video frames show some of what this aerial camera took in during a test flight, including takeoff [a], the climb out over the grass runway [b], gentle banking turns over the lakeside airfield [c and d], the turn onto the crosswind leg of the landing pattern [e] and the final approach [f]. To view the full video, visit http://spectrum.ieee.org/geek-life/hands-on/diy-eye-in-the-sky-video.

PHOTOS: DAVID SCHNEIDER

Another electrical gremlin presented itself in the form of a disturbing jitter in the servo used to point the camera, which showed up when the video transmitter was switched on. After some experiments, I found the best solution was simply to swap out this particular servo for one of a different brand.

Although the basic kit, video gear, and motor upgrades cost less than $500, the number of additional bits and pieces I had to accumulate was substantial. In the end, to get a complete FPV setup working cost about $800—and that doesn't cover the components I had on hand at the start, including most of the radio-control gear, a small LCD monitor for viewing video in the field, and a tripod on which to mount the monitor at eye level.

All in all, expect to sink at least $1000 into it if you're starting from scratch. Also, plan to put in a lot of time up front learning to fly radio-controlled planes in the usual fashion, which takes some dedication and in most cases an instructor's help.

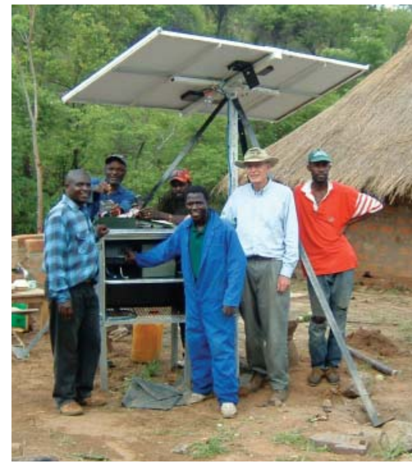
As soon as I took control of this little plane in FPV mode, though, any qualms I might have had about the time and expense swiftly disappeared. Wow! It was great—and it felt very much like flying for real. Minor video dropouts aside, the view was superb. And in some ways it proved easier than flying a radio-controlled plane in the usual way. The hardest part, I found, was judging the plane's altitude. So I added the guts of an altimeter watch to the nose so that the camera could see the altitude displayed. Now, with a little coaching from my copilot, I'm even able to land the thing while in FPV mode.

Although this seems like a lot of technology to be throwing into a model airplane, it's really quite modest as these setups go. Some FPV enthusiasts outfit their planes with GPS receivers, air-speed indicators, gyro stabilization, even autopilots. And they send real-time data on speed, altitude, heading, and battery voltages back to the ground and view it along with the video feed using jazzy on-screen displays.

Next on my agenda is practicing aerobatic maneuvers—loops, rolls, Immelmann turns—which in FPV should be straightforward and promise to be a thrill. I can't wait. Move over, Chuck Yeager, I'm fixin' to tear up the sky.

—David Schneider

careers



JESUIT ENGINEER: Lammert B. Otten installs a solar pumping system [above] and solar panels [left]. *PHOTOS: LAMMERT B. OTTEN*

ENGINEER ON A MISSION

A Jesuit priest and electrical engineer finds a new calling in Africa

As both an electrical engineer and a Jesuit priest, Lammert B. "Bert" Otten can lead a spiritual retreat just as easily as a dam-building project in Zambia. "As an engineer," he says, "you're cocreating with God to make life better for people."

Zambia has been Otten's adopted African home since 2005, when he retired from the University of Seattle. As a consultant in appropriate technology for the Diocesan Promoters Office in Monze, about 180 kilometers southwest of the capital city of Lusaka, he has installed solar-powered water pumps for irrigation, solar vegetable dryers, solar lighting, and refrigeration. He has turned the oil from the seeds of local plants, such as jatropha, into biofuel, soap, and candles. And, yes, he's built a dam—on the Ngwerere River.

As if his retirement weren't busy enough, Otten also uses available materials to solve smaller problems. There's the lamp he made by covering a cardboard toilet-paper roll with an inside-out potato chip bag as a reflector; the solar water distiller he made from glass, poly film, conduit pipe, and a plastic water bottle; and the battery-charging windmills he fashioned from discarded plastic sewer pipes. Otten also hitched LEDs (donated by stateside friends) to flashlight batteries (ditto) as a cheap and safe alternative to burning diesel fuel or candles in a grass-roofed hut.

"Many people in Zambia are living on a dollar a day or less, so cost is a big thing for them," says Otten. He's now working on a battery recharger made out of refrigerator magnets and coils from telephone dialing equipment. "You wave the magnets around the wire coil and get the electrons moving enough to light LEDs," he says.

He also mentors local high school students; last summer he initiated a Seattle University Engineers Without Borders student group trip to the Zambezi River to build a water pump run by river current.

For his efforts in appropriate technology, the University of Missouri College of Engineering, in Columbia—one of Otten's many alma maters—gave him a Missouri Honor Award for Distinguished Service in Engineering.

As a child in St. Louis he relished making crystal and one-tube radios in his basement. At the same time, he adds, "there was always something about my personal relationship with God. I kind of felt called to the priesthood but didn't want to do it. Then, in high school, I got to know the Jesuits, their lifestyle, intellectual discipline, and mission work in the developing world. I realized I could do things like that in relation to technology, and it all tied together."

Otten started at the Jesuit-run St. Louis University as an electrical engineering major in 1950 but entered the Jesuit seminary three years later. He ended up with, among other degrees, a licentiate in sacred theology from the University of Saint Mary, in Kansas, and a Ph.D. in EE from the University of Missouri.

Otten first visited Zambia in 1994. Now 77, he lives in a Jesuit compound containing a high school, hospital, radio station, and staff living quarters within walking distance of the village of Chikuni. Africa seemed a natural choice for retirement. "Most of my contacts were in Zambia, and the needs in Africa were so much greater," he says. "One fellow, orphaned at 10, worked his way through teachers college making and selling LED lights," says Otten. "Now his life is different." —Susan Karlin

technically speaking

BY PAUL McFEDRIES

Carbon Copy

Climate is generating a lot of linguistic heat.
—Technically Speaking, *IEEE Spectrum*, August 2006

CLIMATE CHANGE was a hot enough topic that I wrote about it in this column in 2006, but recent polls show it's no longer a major component of the average person's stress portfolio. Was global warming just another faddish obsession? We can look to language for an answer—new words are the cultural by-products of our preoccupations. And sure enough, while the idea of climate change may be on the back burner, it's clearly on high heat, because new words and phrases are still bubbling up.

Talk about climate change often starts with carbon dioxide—calculating one's *carbon footprint*, weighing the pros and cons of *carbon offsets*, or debating the ethics of *carbon trading*. But when concern becomes obsession, a new class of environmentally conscious person is born: the **carborexic**, a person who obsessively minimizes his or her use of carbon.

Even if few people suffer from **energy anorexia**, or **carborexia**, as it's also called, a recent survey showed that fully 7 percent of Americans are hard core about recycling and reducing their carbon output. Researchers have dubbed them **dark green**. Many in this category worry about their **cookprint**, the energy they use and the waste they produce while preparing meals. The use of the term *footprint* to refer to the impact of human activity on the environment is about 30 years old. You're probably most familiar with the phrase *carbon footprint*, but older variations on the theme are *ecological footprint* and *environmental footprint*.

A related idea is the **walkshed**, the area that a person can comfortably or conveniently cover on foot. This word is an urban take on *watershed*, the area of land that drains into a river or other large water source. A similar term is **foodshed**, which is the area where a person or family can obtain locally grown food. The goal is to reduce your total **food miles**, the distance that a food item travels from its source to the consumer, and the best way to do that is to become a **locavore**, a person who eats only locally grown food. This is just one facet of being an **ethical eater**, someone who only or mostly eats food that meets certain ethical guidelines, particularly organically grown food and humanely raised meat, poultry, and fish.

Your average **ecosexual** (a single, environmentally conscious person with a strong aesthetic sense; a metrosexual in Birkenstocks) does his part by **precycling**—purchasing products based on how recyclable they are—and by cycling everywhere, rain or shine, perhaps using a **sport utility bike** (or **SUB**), a bicycle that's been extended so it can carry an extra passenger or extra cargo. On the rare occasions our ecosexual friend finds himself behind the wheel, his **eco-driving** minimizes fuel consumption and emissions. Many **eco-drivers** are also **hypermilers**—people whose driving technique conserves fuel by maximizing gas mileage.

Our hero may also express his **ecosexuality** by using only **cleantech**—technology that itself is environmentally friendly or that helps reduce environmental problems—as well as by supporting **pay-as-you-throw** (**PAYT**) programs (which charge a fee based on how much garbage a household or business generates) and **feebates** (government programs designed to reduce energy use and pollution by levying fees on fuel-inefficient vehicles and offering rebates on fuel-efficient vehicles). He may even happily join in with a **carrotmob**, an event where people support an environmentally friendly store by gathering en masse to purchase the store's products.

If there's a downside to all this fuss about the climate, it's that it can lead to what some people have dubbed **climate porn**: extreme or alarmist language or images used to describe the effects of man-made climate change. This leads to **eco-anxiety**, which is worry caused by concerns about the environment, and **threat fatigue**, where people ignore or downplay a possible threat after being subjected to constant warnings about that threat.

Perhaps that's why people tell pollsters that climate change is no great concern. After years of dire warnings, apocalyptic predictions, and the-sky-is-falling tirades, maybe they're just tired. ❑

J.D. KING

DREAM JOBS '10

SPECIAL REPORT

SOME CAREERS PROCEED along a nice, neat path. But the 10 technologists in this year's Dream Jobs report found their journeys full of unexpected twists, dramatic surprises, and what probably looked to others like complete about-faces.

Take Rick Armstrong. He started out as a sound engineer, but now he spends his workdays aboard small aircraft, tapping away at his laptop to create detailed 3-D maps.

Bob Marsh, too, has had a long, strange trip. Remember the Homebrew Computer Club? Marsh's work with the group earned him a place in computing history. These days he trots the globe installing computer centers in the most isolated regions. Ernst Völlm, who began his career building a bobbin winder for a textile company, now designs the most advanced scuba computers available.

Ronald Thomas used to work on instruments to study the upper atmosphere; now he seeks out erupting volcanoes in search of lightning. José Losada didn't grow up thinking he'd someday write code for the telescope with the largest light-collecting mirror in the world. But that's what he does, in the sun-washed paradise of the Canary Islands. Working for a biotech firm, Brian Gallagher spent his evenings developing a truck-suspension control system. His sideline morphed into a full-time gig overseeing electrical systems for a remarkably aerodynamic electric car.

Dream jobs can come when you least expect them. Hiroko Ohmura always loved pianos, but as a computer scientist she never expected to design one—until her employer, Yamaha, surprised her with a transfer from IT to the digital musical instruments division. Henrik Sørensen had been unemployed for months when he landed his dream job designing energy systems for sustainable buildings. And Jacob Melvin's grades were so poor he worried he wouldn't graduate college. But then recruiters for DreamWorks Animation SKG offered him the position he had always dreamed of.

Finally, consider Catherine Mohr. At 27, she was working on some of the world's most advanced electric vehicles—surely a dream job. But Mohr decided she'd rather help doctors and their patients. So she went to medical school, and now she's creating cutting-edge tools for robotic surgery.

Has your path led to the job of your dreams? Write and tell us about it at eedreamjobs@ieee.org.

DREAMWORKER

Once a struggling student, now he's a trainer of dragons at DreamWorks Animation

IT'S MARCH 2007, and there's Jacob Melvin, a senior computer science major at the University of Colorado at Boulder. He's got a two-point-something grade point average, and he's barely hanging on in a required class. He's not worried about trying to land his dream job. He's worried about graduating.

Flash forward a few years. Melvin is now a technical director for DreamWorks Animation SKG in Glendale, Calif. He worked on *Kung Fu Panda* and is finishing up *How to Train Your Dragon*, due to hit theaters next month. He spends his days on the spectacular DreamWorks Animation campus, where fountains and streams wander through olive groves, palm trees shelter a beach volleyball court, and movie stars and famous directors drop by for screenings at the 148-seat theater. Emmys and Oscars glitter above cool tile floors, and the stunningly good food in the cafeteria is free.

Some guys have all the luck, huh?

Actually, it wasn't luck that landed Melvin the job. It was obsession. His grades in college were marginal not because he wasn't interested in studying computers but rather because he was *too* interested in computer applications that weren't in the curriculum. He liked video games—particularly the animation sequences between levels—and wanted to create them. These days, some 250 U.S. colleges offer majors in video-game design. Not so then.

As a computer science major, Melvin quickly found out that his professors expected him to study computer security or networking systems, because that's where local jobs were. That "made me want to get a new major," he says, but instead he stuck with it, adding classes in media arts (targeted more toward film majors) and graphic design. Finally, in the last of his four years, the university offered a single class in game design, focused on educational simulations.

He took the course and developed a strategy game based on the U.S. Revolutionary War. It was the first time he'd ever built a game end to end. Previously, he'd spent his spare time on small projects related to game design—he made a 3-D rain simulator, for example.

The experience was disillusioning. "I liked the graphics part but not all the minute details," Melvin says. "You have to think of everything a player could do and make sure that you have that case covered. That can get really tedious."

Meanwhile, for his senior project he was working with a local company designing a Web-based tool to convert still photographs into comic-strip art. Melvin wrote software to segment the photographic image,

ICONS BY JASON LEE

Jacob Melvin

IEEE Member

AGE 26

WHAT HE DOES Writes code and designs tools for computer animation.

FOR WHOM DreamWorks Animation SKG

WHERE HE DOES IT In a re-created California mission in Glendale, Calif.

FUN FACTORS Works in a cool environment on movies that could become animation classics. Meets film stars and famous directors.

CREATIVE CODE: Jacob Melvin's software skills landed him a job at DreamWorks Animation.

IMAGES: DREAMWORKS ANIMATION; PHOTO-ILLUSTRATION: STATIK DIGITAL grouping pixels together to form objects. He found the task fascinating but had no idea where it might lead.

In March 2007, Melvin flew to Columbus, Ohio, for the National Society of Black Engineers' career fair. He planned to hand out résumés and then not think about the job hunt again until he was sure he would be graduating.

Passing a booth, he picked up a brochure and started reading an article about the making of the movie *Shrek*. A man stepped forward to chat, asking him questions about his interests and education. "I kept answering his questions, but I didn't look up, because I was interested in the article," Melvin says. Finally, he finished reading and only then noticed that the man was wearing a polo shirt with the *Shrek* logo. The lightbulb went on. "This guy's from DreamWorks and is interviewing me," he thought.

He gave the DreamWorks rep his résumé. The next day, he met with several more managers. By the end of the weekend, the DreamWorks folks told Melvin to expect a job offer in the mail.

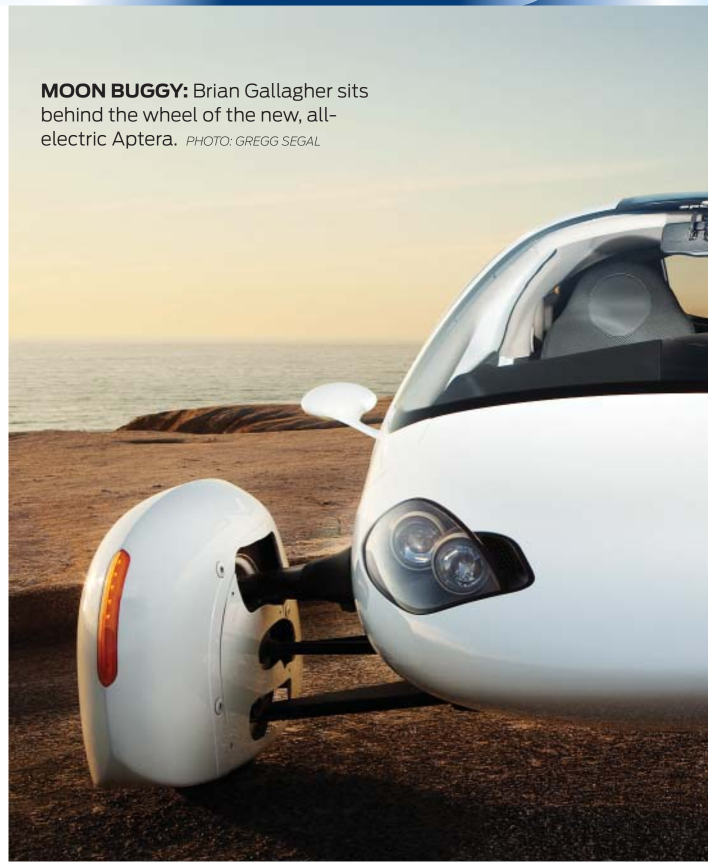
"I would say my senior project helped to get them to take me seriously," Melvin says. "And I told them that ever since high school the only option for me was graphics"—that he'd always intended to use everything he learned studying computers to do something with graphics.

Today, as a technical director, Melvin works with a team of animators. On a big movie—with 50 or more animators—he'll be one of two or three technical directors. The animators are often trying to do things that have never been done before, and that causes problems. Melvin's job is to fix those problems so the movie can get made, on time and within budget. He might rewrite old code, build a new software tool, or create a graphical user interface to let an animator work faster.

Melvin cites a recent example from *How to Train Your Dragon*. The character Stoick has a complex beard that needs to move naturally. This movement had to be simulated to make sure that the beard didn't bump into things in the scene, but simulating Stoick and his beard took up to six times as long as it did for a simpler character. To make things worse, the existing software ran the individual character simulations sequentially, so Stoick's appearance in a scene slowed the whole process down dramatically. Melvin rebuilt the pipeline to run multiple character simulations in parallel, so by the time the computer completed running Stoick, all the other character simulations were complete as well. "Future movies will be better off because we have tools in place for these kinds of setups," he says.

Melvin intends to stay in the movie industry but may branch out from his current role; he's intrigued by crowd programming and by character rigging, which basically involves writing the code that defines how an animated character moves.

For now, though, at age 26, he's pretty pleased with his career. "*Kung Fu Panda* and *How to Train Your Dragon*, I think, are movies that will be classics. My kids will watch them. Which means that there are millions of other kids that are going to be watching those same movies over and over. And I was actually a part of them." —Tekla S. Perry



MOON BUGGY: Brian Gallagher sits behind the wheel of the new, all-electric Aptera. PHOTO: GREGG SEGAL

AUTOMOTIVE

ELECTRIC-CAR SURFER

An unlikely automotive engineer oversees all the electricity at a revolutionary vehicle start-up

EVEN AFTER WORKING ON THE thing for years, Brian Gallagher can't forget how astounding the sight of an Aptera in the wild can be. When one came barreling toward him and his wife recently, he says, he yelled just as loudly as she did. "It was shocking."

A two-seater on three wheels with a teardrop shape and a drag coefficient of 0.15 (better than any other production car), the Aptera sure sticks out—as does Gallagher, who developed the car's electrical systems. At 30, he's undoubtedly the youngest—and the only visibly tattooed—engineer to be entrusted with such a heady responsibility. Yet before joining the three-year-old start-up in Vista, Calif., Gallagher had never had any special interest in cars, electric or otherwise.

Born into a military family, growing up all around the world, Gallagher was always drawn to things technical. He remembers

spending hours taking apart Japanese toy robots and putting them back together to do new things. In 2003 he got his EE degree at the San Diego campus of the ITT Technical Institute and then stayed on in that city, taking a job designing automation systems for a biotech firm and indulging his taste for sun and surfing.

Gallagher soon developed a side project to build an intuitive touch-screen user interface to give truck drivers finer control of the air suspension of the tractors or trailers they were towing, for a more level ride. While working on it, he taught himself the mechanics of auto-suspension design and tested his evolving control system by using his 2002 Ford Mustang GT as a test "mule." It turned out his interests dovetailed with those of a colleague at the biotech firm: Steve Fambro, also an EE, who'd long wanted to design an ultraefficient car and was developing body designs for one. Fambro knew his car would need a suspension control that could minimize drag by adjusting the car's angle of attack, just as a surfer does by angling his board to keep it poised on the curl of a wave. So by the summer of 2004 the two of them had fallen into a habit of working every night on their respective prototypes, then comparing notes the next morning.

Gallagher moved to Arizona to be near the prospective distributor of his truck suspension system, but the project fizzled, so in 2005 he returned to southern California to work as a contract engineer. Fambro, then designing the Aptera prototype, asked Gallagher to redo his air suspension for the car's special, drag-avoiding needs—without pay until money came through. Two years later, after Fambro had secured a second round of development funding, he hired Gallagher as an R&D engineer for Aptera Motors, later dedicating him to high-voltage systems. A year and a half later, Fambro promoted him to his current position, electrical engineering project manager.

Brian Gallagher

AGE 30

WHAT HE DOES
Oversees design of all electrical systems for a new electric vehicle.

FOR WHOM
Aptera Motors

WHERE HE DOES IT
In and out of the test-car garage in Vista, Calif.

FUN FACTORS
Frequently test-drives the world's most aerodynamic car, one so startling that jaws drop whenever it passes.

Since then, Gallagher has developed an appreciation for the rigor of automotive engineering. "What gets designed not only has to work right," he says, "but it has to be ultrareliable for 10 years *and* it's got to be cheap, not like in, say, aerospace."

His day is a flurry of one-on-one conversations and meetings with teams for each major subsystem. A typical meeting will involve five full-time engineers, six or seven software consultants, and a few more engineers from parts vendors. To keep teams on their timelines, he stays abreast of every aspect of each design, ensures that all systems are properly integrated, and sometimes "dives into problems to understand them" so he can help guide individual engineers.

These days, on the high-voltage side, the traction team is finalizing the 22-kilowatt-hour battery-pack design and also the layout of cabling. The power electronics team is refining the control software that modulates power from the 75-kW electric motor and recharges the pack when the regenerative brakes kick in; the team's goal is to make the transitions imperceptible to the driver. Other teams handle the DC-DC voltage converter and the built-in battery charger.

On the low-voltage side, the engineers have integrated almost everything into the car's distributed network. Their control logic must shuffle data among a variety of sensors, switches, electronic control units, and accessories: lights, wipers, instruments, door locks, the key fob, and the car's infotainment system.

Gallagher is proudest, he says, of "convincing Steve we could create a PC platform in the vehicle that could be customized with software apps." The idea is to provide drivers with data to help them optimize their driving, making a game out of using as little energy as possible. That's "the killer app for Aptera," he says.

The Aptera 2e, as the car will officially be known, will monitor its energy use and compare it to both the selected driving style—fast and furious, say, or measured and thrifty—and the distance to the destination. If the battery's charge isn't enough to get the car that far, the car will offer the driver options to increase the range. It might, for example, suggest that the driver stop driving like a maniac, offer to dial down power to the air-conditioning, or even lower the volume on the car's sound system. Gallagher points out that drivers can set parameters as specific as the suspension heights of each wheel by using virtual sliding "levers" on the touch screen.

The final production version of the 2010 Aptera 2e will be unveiled later this year, and mass production will follow several months later. The car is expected to accelerate to 60 miles per hour (about 100 kilometers per hour) in 10 seconds and have a 100-mile range between charges. Still, its two seats and startling shape may limit its sales to true electric-car devotees, wealthy gadget freaks, and futurists. More than 4000 have already put deposits down on the car, even though its price is vaguely quoted as "between US $25 000 and $40 000."

Gallagher himself still drives his black 2002 Mustang GT with a V8 engine, which despite its life as a mule has only 35 000 miles on it. But his commute is short; he lives with his wife and three sons just 10 miles away. Nowadays, instead of surfing, he runs.

What keeps him going? Sure, there's the green aspect. "This has the potential to be a very revolutionary car," Gallagher says. But then he grins at how people have reacted to a design they couldn't imagine until they saw it. Gallagher enjoys building stuff that makes people scream in surprise. —John Voelcker

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ADVENTURE

ENGINEER VERSUS THE VOLCANO

He tracks the weird and vivid bursts of lightning from erupting volcanoes

LATE ONE NIGHT LAST MARCH, the icy peak of Mount Redoubt in south central Alaska erupted, sending thick plumes of ash and steam more than 10 000 meters into the air. It was a nightmare for local residents and pilots but a dream come true for Ronald Thomas.

Thomas, an electrical engineering professor at the New Mexico Institute of Mining and Technology, studies lightning, particularly the lightning that accompanies volcanic eruptions. Mount Redoubt had started rumbling two months earlier, and just two days after the first shudder, Thomas, one of his graduate students, and a colleague were on a plane to Anchorage. Trudging through swirling snow, they set up four sensing stations around the mountain that would help them create 3-D pictures of the lightning inside the volcano's ash plumes.

For Thomas, the trip was a heady rush. "Alaska is always fun, even in the winter," he insists. "That's when tourists aren't around."

Lightning is, of course, the sudden release of a massive buildup of electrical charge in the atmosphere. But that simple description glosses over many unsolved mysteries: why, for instance, only some storms produce lightning; why some lightning discharges up from clouds rather than down; and why certain types of volcanoes—but not all—give off spectacular bursts of lightning. Getting to the heart of such questions is Thomas's quest.

He first got hooked on lightning as an 8-year-old: His father, a high school science teacher, had "a machine that you cranked and it made sparks like lightning," he recalls. He spent many happy hours cranking that machine. By high school, he knew he wanted to be an electrical engineer.

In 1961, he entered an engineering co-op program at New Mexico State University in Las Cruces. During a nine-month stint at a naval communications station in the Philippines, Thomas tracked transit satellites, the forerunners of GPS satellites, by measuring the Doppler shift in their radio signals. Later he followed sounding rockets at NASA's Wallops Island facility off the coast of Virginia.

He graduated with a BSEE in 1966 and moved on to Utah State University, where he used rockets to study chemical reactions in the upper atmosphere. By 1973 he had completed a master's in atmospheric physics, a Ph.D. in electrical engineering (also from Utah), and a postdoc at the University of Pittsburgh. He then settled down at the University of Colorado at Boulder, designing and building rocket-launched instruments to study ozone in the mesosphere, the layer of atmosphere directly above the stratosphere.

In 1989, he joined the faculty of New Mexico Tech, in Socorro, where an abundance of thunderstorms has long drawn researchers interested in lightning. He helped develop the portable lightning sensors that the National Weather Service and the National Severe Storms Laboratory now use, downsizing the equipment to fit into picnic coolers. A typical lightning bolt unleashes not only light and sound but also millions of current impulses that radiate radio

Ronald Thomas

IEEE Member

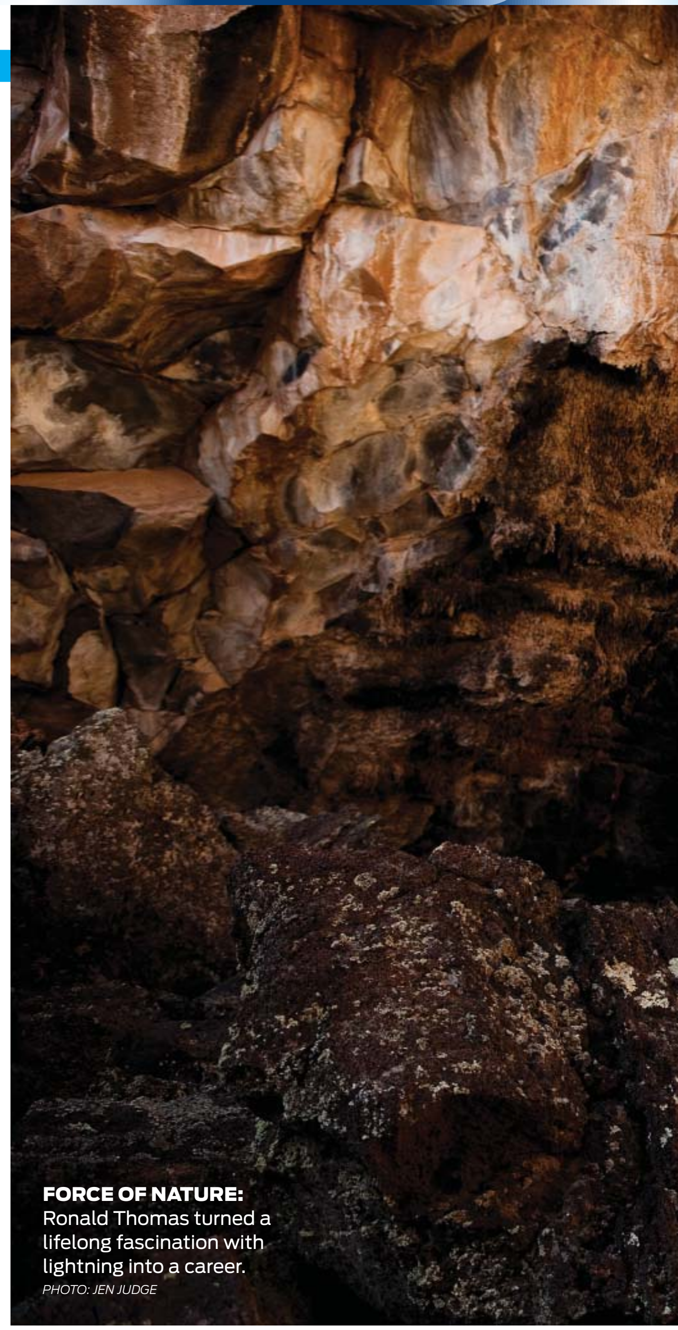
AGE 66

WHAT HE DOES
Studies lightning emitted by volcanoes and thunderstorms.

FOR WHOM
New Mexico Institute of Mining and Technology

WHERE HE DOES IT
Active volcanoes worldwide once or twice a year

FUN FACTORS
Flew over Mount St. Augustine in a helicopter while it was shrouded in steam; one of his favorite books is *Volcano Cowboys* by Dick Thompson.



FORCE OF NATURE: Ronald Thomas turned a lifelong fascination with lightning into a career.
PHOTO: JEN JUDGE

waves over a broad range of frequencies, from a few kilohertz up to a few gigahertz. To record the impulses' times and magnitudes, the lightning sensor has an antenna and receiver, a computer, a timing interface, and a GPS receiver.

About four years ago, Thomas and a few colleagues formed the world's only research team devoted to the curious phenomenon of volcano lightning. At the time, experts assumed volcano lightning was identical to thunderstorm lightning—branching flashes that last about half a second. But the team soon discovered there was much more going on. At the January 2006 eruption of Alaska's Mount St. Augustine, they observed a continuous series of millisecond-long explosive sparks right at the mouth of the volcano as it started to erupt. The May 2008 eruption at Chaitén, in southern Chile, brought another surprise: horizontal lightning stretching 8 kilometers across.

At Mount Redoubt last year, Thomas and his coworkers were able, for the first time, to gather data starting with the very first eruption. To their astonishment, they discovered that lightning flashes accompanied every single one of the more than 20 major eruptions that occurred over 13 days.

Picking optimal spots for the sensors is critical, they've learned: The ideal location has a line of sight to the plumes above the volcano, as well as access to electrical service and the Internet. The researchers sometimes find themselves knocking on doors to get permission to set up their equipment in people's backyards. The hard part, Thomas says, is convincing them "we're not spying for the tax man."

At Redoubt each lightning flash created thousands of radio impulses that hit the sensing stations' receivers at different times. By correlating those times and triangulating the distances, the sensor array pinpointed the location of each impulse. Thomas used the data to create 2-D maps of the charge structure inside the volcano's ash cloud. The maps show where the lightning originated and how it spread. Thomas's goal is to understand how and why the charge buildup occurs in the first place.

It's all so fascinating to Thomas that he says he'd plan every vacation near a volcano if he could. Sure, camping in the deserts of New Mexico has its charms, rattlesnakes notwithstanding. And yes, the natural forces he studies are violent and, to many people, terrifying. But nothing compares to the thrill of getting near an active volcano, he says. "The most dangerous part of the trip is really the driving." —Prachi Patel

KEYS TO SUCCESS: Hiroko Ohmura translates classical musical instruments into digital form.
PHOTO: BRUCE OSBORN

MUSIC

KEYBOARD MAESTRO

At Yamaha she creates the digital pianos of the future

THE GLEAMING GRAND PIANO looks like others I've seen. But with utmost politeness, Hiroko Ohmura informs me that I'm mistaken. With that, she attacks the keys, and the notes of Beethoven's Sonata No. 8 in C minor, the famed "Pathétique," fill the vast auditorium. I'm entranced. When she's finished, she points inside the ebony cabinet: There are no strings; the sound comes from an array of speakers.

"You like the music?" she asks. Reaching below the keyboard, she removes a USB thumb drive from a small control panel. "You can take it with you."

We're at Yamaha Corp.'s headquarters in Hamamatsu, Japan, an industrial city about 250 kilometers southwest of Tokyo. As a manager in Yamaha's professional audio and digital musical instruments division, Ohmura dreams up the next generation of keyboards that musicians will seek for their studios and consumers will crave for their living rooms. She's just demonstrated what's probably the most advanced digital piano ever created. Called the AvantGrand, it's engineered to replicate the sound and feel of a concert-quality grand—except it's smaller, much cheaper, and full of digital tricks.

"This piano," the amiable Ohmura says, her eyes fixed on the keys, "I know all about it." She should; she helped design every part of it.

Ohmura, who is 39, says she loved playing piano as a child but never imagined she would one day work with pianos. "Or play them at work," she says with a smile. Growing up in the Hamamatsu area—where in 1887 Torakusu Yamaha started a piano business that would become a Japanese powerhouse—she of course knew all about her hometown company. And after graduating in 1992 from Yokohama National University, where she studied psychology and computer science, she applied for and got a job at Yamaha. The job, however, involved not musical but computer keyboards: Ohmura was a systems engineer in Yamaha's IT department, tending to networks and writing software.

One day in 1997, her supervisor told her she was being transferred to the digital instruments division. The news floored her. Personnel transfers are common in Japanese companies, but Ohmura says she never asked for the change. "I transferred to this division by accident," is how she puts it.

Whatever the reason, the move made her "very happy." She started out designing LCD interfaces for electronic keyboards. She was then promoted to product engineer and worked on the popular Clavinova series of digital pianos. Her job became more managerial, but Ohmura kept a hand in the design department. Her name appeared on several patents, including one for a keyboard display that rendered a bouncing ball above the keys, showing players which ones to press.

In 2007, faced with fierce competition in the piano market, Yamaha drastically revised its business strategy. The new plan called for developing products that combined the company's acoustic and electronic expertise, two areas that had operated independently. The idea for the AvantGrand, a grand piano rendered in digital form, began to take shape. And Ohmura's career took a grand leap: Named project leader, she would be responsible for overseeing every detail of the new instrument.

Even for Yamaha, the world's largest manufacturer of musical instruments, the AvantGrand was ambitious. Ohmura's team started by taking a complete acoustic inventory of a traditional grand. Engineers placed a CFIIIS, Yamaha's top-of-the-line concert model, in a soundproof lab and attached it to a kind of robotic pianist. This machine pressed each of the 88 keys multiple times with varying force while the engineers sampled the notes from four locations within the cabinet. When you press a key on the AvantGrand, recordings of those samples emerge from the instrument's four midrange speakers, four tweeters, four subwoofers, and 16 power amplifiers.

Ohmura also supervised the construction of the piano's body. An acous-

Hiroko Ohmura

IEEE Member

AGE 39

WHAT SHE DOES
Leads the design and marketing of advanced digital musical instruments.

FOR WHOM
Yamaha Corp.

WHERE SHE DOES IT
Hamamatsu, Japan

FUN FACTORS
Plays piano at work; gets to test new musical-instrument prototypes; interacts with famous musicians.

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DREAM JOBS 2010

tic piano is an intricate masterpiece of levers, weights, dampers, and hammers that hit strings to produce sound. The innards of the AvantGrand are similar, but instead of strings, its hammers hit padded rails; optical sensors capture each hammer's movements to trigger the notes. From the player's perspective, the keyboard action feels remarkably similar to that of an acoustic piano.

For added realism, the company fitted electronic resonators—two under the keyboard and two behind the music stand—that make the piano's keys, pedals, and cabinet reverberate like those of a real grand. As you play, you can literally feel the music flowing through your hands and feet.

"When I tried the first prototype," Ohmura says, "I almost cried."

Technology was just part of the challenge, she says. There was also the human side. Engineers in the acoustic piano division weren't used to working with their counterparts in the digital instruments division. It was up to her to bring them together. She held hundreds of meetings to champion the project and build consensus. Important negotiations also happened in the background, in what the Japanese call *nemawashi*, or laying the groundwork. To get it all done, Ohmura was at the office by 8:30 in the morning, sat in meetings for most of the day, and spent her evenings poring over market reports and customer surveys, usually leaving work after 10 p.m.

Her efforts paid off. "Our two divisions are very close now," says Roger Manners, a deputy general manager in the piano division. "She should be a politician," he quips.

And the AvantGrand, which hit showrooms last year, was an instant success. Whereas a 2.75-meter-long concert grand sells for over US $100 000, Yamaha's digital grand costs $20 000 and is just half the size. What's more, it never has to be tuned, and players can lower the volume or use headphones to avoid annoying the neighbors. Though concert pianists may not be ready to make the switch, Yamaha is awash in orders from conservatories and from piano enthusiasts with Tokyo-size apartments.

Ohmura is now working on a new keyboard project—"top secret," she says—and her routine is more frantic than ever. But she's not complaining. Quite the opposite. She enjoys the pace and the opportunities her job brings, she says, and she's always eager to meet the world-class pianists whom Yamaha invites to try out its new models. Jazz pianist Bob James liked the AvantGrand so much he used the piano in concerts throughout Japan last April. In the audience at his performance in Tsukuba sat a young Yamaha engineer, smiling to herself. —Erico Guizzo

DO GOOD

HACKING FOR HUMANITY

He brings the hacker ethic and Internet access to the far corners of the globe

He attained geek immortality by coinventing the Sol-20 personal computer in the mid-1970s. He was a key member of the legendary Homebrew Computer Club and a recurring character in Steven Levy's 1984 book, *Hackers*. So you'd think that nowadays Bob Marsh might be tripping the light fantastic like fellow personal-computer pioneer Steve Wozniak, or at least kicking back and enjoying retirement.

But Marsh, 63, doesn't kick back. Fueled by coffee (really good coffee) and surrounded by a cadre of earnest young engineers, he's hard at work bridging the digital divide. By any means necessary.

"What's one of the key differences between someone in a village in Africa and someone here in the United States, even a poor person in a poor community?" he asks. Answer: "Google. If you have Internet access and Google, you can find anything."

As one of three cofounders of the San Francisco–based nonprofit Inveneo, and with funding from partners like Advanced Micro Devices, Cisco, and the United Nations, Marsh trots the globe to establish new computer centers in some of the world's most isolated and undeveloped locales. In partnership with local organizations, he's worked lately in Kenya, Mali, Rwanda, and Bangladesh.

"If you're in a capital city in any third-world country, say, Kinshasa or Kabul, you have all kinds of technology available," says Marsh. "But it's

SHARING KNOWLEDGE: Bob Marsh trains engineers the world over, including these in Cameroon. PHOTO: INVENEO

Bob Marsh

IEEE Member

AGE 63

WHAT HE DOES
Installs computer centers around the world.

FOR WHOM
Inveneo

WHERE HE DOES IT
Everywhere

FUN FACTORS
Has developed an amazing capacity to resist jet lag, but not necessarily food poisoning.

pretty hard to get access to technology at some little village in the middle of the jungle."

On a sunny October day in San Francisco, Marsh is brainstorming with coworkers at Inveneo's loftlike office at the edge of the city's downtown district. He'll be gone for the next four weeks, and he'll schlep from one side of the Democratic Republic of Congo to the other, starting in Kinshasa and ending in Bukavu, near the border with Rwanda.

The team has laid out Marsh's tasks and talked about what he should take with him. He doesn't travel light. As part of his job setting up installations, Marsh often carries with him 30-kilogram Pelican cases crammed with compact servers, disk drives, monitors, cables, and circuit breakers.

Marsh's work with Inveneo fits perfectly with the hacker ethic espoused at Homebrew meetings: Don't just spur innovation—use it to make people's lives better. For example, sensing a business opportunity in the wild and woolly early days of personal computers, in 1975 Marsh started a company called Processor Technology Corp., which made 4-kilobyte memory boards for the primordial Altair. Later that same year, he collaborated with Lee Felsenstein to create the Sol-20, now enshrined at the Smithsonian Institution.

Processor Technology became part of Silicon Valley lore, but it didn't exactly mint money for Marsh. For the next 20 years, he went from start-up to start-up, with a brief detour into California state politics on behalf of the Green Party. Then, in 2001, while Marsh was working as director of hardware development at a medium-size wireless-equipment manufacturer, the dot-com bubble burst, and he was out of a job.

At that point, his old hacker pal Felsenstein brought him into the Jhai Foundation, which was bringing bicycle-powered computers and Internet access to a small village in Laos [see "It Takes a Village," *IEEE Spectrum*, September 2003, http://spectrum.ieee.org/computing/it/it-takes-a-village]. But within a year he'd soured on Jhai—he won't say exactly why—and decided to strike out on his own. In 2002, he founded Inveneo with former Jhai volunteers Kristin Peterson and Mark Summer.

"Silicon Valley is a real rat race, and it can get to you," Marsh says. "By the time I got to my late 50s, I was thinking, can I do this whole start-up thing, working 16-hour days six or seven days a week? Again?" He laughs. "I wanted to do *this* kind of work. Time to give back, you know, what I've learned." It also helped that he had some measure of financial security after receiving a modest inheritance from his mother, so he was able to go without a paycheck at Inveneo for the first two years.

His first creation was the low-power Inveneo Computing Station, assembled from off-the-shelf parts. Optimized for operation in tropical conditions, the computer and display consume about 17 watts total. They can run on either 100/240-volt AC or 12-V DC, allowing them to be used with wall current, solar panels, or 12-V batteries. The station can run either Ubuntu Linux or Microsoft Windows XP.

So far, Inveneo and its local partners have installed these and similar systems in more than 300 communities in 23 countries. Now you can add the good people of Bukavu to the list. Marsh spent three weeks toiling in the drenching downpours of eastern Congo, because, as he put it in an e-mail, "Failure Is Not An Option! I returned to the hotel tonight about 10:15pm after an exhausting but fulfilling day... IT'S ALL WORKING!!!" And those are about the sweetest words a real hacker could utter. —Harry Goldstein

MAP QUEST: Rick Armstrong gets ready for another day at the office. *PHOTO: AARON HEWITT*

MAPMAKING

FLYING MATHEMATICIAN

His adventure flights over rough mountains yield stunningly accurate maps

RICK ARMSTRONG IS SNUGGLED up with a laptop in the cluttered space that was once the backseat of a six-passenger Cessna 206. Twenty-five hundred meters below, sun-splashed Portland, Ore., slowly dissolves into the Tolkienesque foothills of Mount Hood. It's some beautiful scenery. But right now, Armstrong's eyes are fixed on his computer, which monitors the images that are streaming in from a camera mounted under the belly of the little plane.

Luckily, he doesn't need to worry about flying. His pilot, an ex–U.S. National Guardsman, expertly guides the plane back and forth in a series of closely spaced lines so as to get full coverage of the territory below—not unlike the zigzagging you might do when mowing a lawn, but on a grander scale. By the end of

the day, Armstrong's laptop will have mapped about 600 square kilometers of land.

After the plane touches down, Armstrong will return his precious cargo—a 160-gigabyte solid-state drive filled with about 7000 high-resolution images of the Oregon landscape—to Urban Robotics, an aerial imaging company in Portland. There, engineers will transform the collected images into 3-D representations of the land that are downright stunning. Using sensor systems and parallel-processing software that it developed itself, the company creates what are known as orthorectified maps, which can be used to measure true distances.

The upshot is that Armstrong, flying in a properly outfitted plane, can in a single day create the kind of detailed elevation and ground maps that used to require weeks or months of processing. Urban Robotics' customers—which include defense contractors, disaster planners, and power companies—need up-to-date, extremely detailed maps.

Urban Robotics hasn't suffered from the recession, but its headquarters aren't housed in sleek steel and glass. Its offices are on the second floor of a charmingly creaky building that seems straight out of "Deadwood"—complete with exposed brick, huge windows, and ancient wood floors that groan under countless layers of varnish.

A glossy aerial photo of the Three Mile Island nuclear power station in Pennsylvania takes up an entire wall. With the outrageous level of detail, you can almost tell the make of the cars parked in a lot near one of the cooling towers. Breathtaking aerial views of national monuments entice potential clients. Hidden away are the maps commissioned by the U.S. military.

CREATING ACCURATE, nicely blended 3-D maps from several terabytes' worth of 2-D images, automatically and on short deadlines, is an enormously complex task. Doing it right and doing it fast (the company's specialty) involves a special sauce of image processing, mathematics, numerical computing, information theory, and parallel computing. Urban Robotics—founded in 2003 by two former Intel employees and an ex–U.S. Defense Department scientist—makes its maps using wickedly complicated signal processing and complex camera systems. That's where Armstrong, a self-described "inveterate geek," comes in: He designs and works on the sensor systems. But he looks as though he should be disassembling motorcycles on a reality show; his goatee and untucked shirt match a similarly untucked attitude.

"Everybody I work with took the TV apart as a kid," Armstrong says, walking into a messy office with floor-to-ceiling windows and filled with electronics gear.

He may have taken the TV apart as a kid, but his path to engineering was by no means traditional. He grew up in Los Angeles. His father, a former pilot, often took him to the airport to watch planes take off and land. "He had a little aviation radio," Armstrong remembers, "and he'd turn it on and explain to me what was happening."

But not long after those trips to the airport, his father left. Keeping Armstrong on the right path fell to his aunt and his uncle, a barrel-chested Scotsman with a handlebar mustache, an Afro, and an excellent collection of vinyl. "At 14, I decided there was no point in going to school anymore," Armstrong says. "I told my aunt I'd get around to it at some point. She told me, 'No, you'll get around to it *now*.' " Dragging him to school by the ear, as he describes it, worked until he was 17, which is when music began to seem a lot more interesting than what he was learning in class.

He left school, started his own metal band, and became chief sound engineer at the Ice House, a former rock club in nearby Pasadena. But even that job became boring for Armstrong, who likes to work out some of his restless energy solving mathematical puzzles, preferably by putting them in matrix form. (He loves linear algebra so much that he watches an MIT professor's online tutorials in his spare time.) When he turned 25, he received a GED certificate and started chipping away at an electrical engineering degree at a local college. When money ran out, he hopped an Alaska-bound Greyhound bus and spent the summer on a salmon fishing boat. He did the same the following year.

On his second trip, he met his girlfriend, an artist. "We spent about 20 hours on that bus together," Armstrong says with a smile. They're still together after 15 years. Although they have moved around quite a bit, they have no plans to leave Portland, a city that Armstrong likes because it affords its residents the rare luxury of not having to drive. And, he says, the summers are outrageously green and beautiful. "But you know, you really have to be into caffeine and alcohol to survive the rest of the year."

ARMSTRONG'S VERY FIRST FLIGHT, in 2004, took him over the Grand Canyon. Next he went to Las Vegas. And it just kept getting better. Most recently, he buzzed Horseshoe Bay, near Vancouver in British Columbia, by helicopter, where he made eye contact with a bald eagle swooping around the chopper while he was parked on the side of a mountain. "My job is half flying and half math," he says. He loves it. "A lot of times in IT programming, you write some software and you get user feedback. But it's really nice to eat your own lunch—you know, see your own code working."

Armstrong and his pilot fly at 2500 meters, because that altitude provides the best compromise between good coverage and good resolution. Also, above 2500 meters looms the danger of hypoxia, a dangerous condition that occurs when the body is deprived of adequate oxygen.

In October, Armstrong and several other Urban Robotics field engineers got the chance to experience what hypoxia is like during training they received at Fairchild Air Force Base, outside of Spokane, Wash. The engineers climbed into a hypobaric chamber, inside which the pressure was abruptly lowered to simulate sudden decompression at 20 000 feet (about 6000 meters). Then they removed their masks for several minutes for some cognitive tests. "It was like an episode of 'Jackass,' " Armstrong says.

Armstrong says they can have his job when they pry it out of his cold, dead hands. "I'm nominally a software engineer, but I also get to dabble in other engineering disciplines," he says. "And I get to do it while riding around in all manner of flying machines!"

—Sally Adee

Rick Armstrong

IEEE Member

AGE 46

WHAT HE DOES
Flies over breathtaking vistas to make ultrahigh-resolution maps.

FOR WHOM
Urban Robotics

WHERE HE DOES IT
In a small plane or in a turn-of-the-20th-century building in Portland, Ore.

FUN FACTORS
For him: linear algebra. For anyone else: buzzing the Grand Canyon, Mount Rainier, the Las Vegas Strip, and other picturesque locales.

MEDICAL

ROBODOC

She already had her dream job designing electric cars, but sometimes dreams change

CATHERINE MOHR WANTED to save the world, or at least a piece of it. But she just wasn't sure how to go about it.

At age 27 she had what most engineers would consider a dream job: product engineering manager at AeroVironment, a boutique firm in Monrovia, Calif., that designs and builds some of the world's most advanced land and air vehicles. She'd helped build cars for Switzerland's Tour de Sol and Australia's first World Solar Challenge, worked on power trains for hybrid cars, supervised construction of a hybrid off-road military reconnaissance vehicle, and started a laboratory to develop fuel-cell systems for aircraft designed to stay aloft for months at a time.

"It was a glorified toy factory," Mohr recalls. "It was just the kind of thing I wanted to be doing."

But in the late 1990s, she started to tire of making incredibly cool vehicles in lots of one or two. "We'd been working with each one of the Big Three U.S. car companies for years. We had built electric prototypes, hybrid prototypes." But the U.S. car companies weren't commercializing these designs.

"I'd been trying to save the world on a grand scale, with energy policy and electric cars," Mohr says. "But there were these huge entrenched political, philosophical problems lined up against being able to just go out and do that. I was tired and frustrated."

So, sitting in her office at AeroVironment, she thought about her options. As a graduate engineering student at MIT, Mohr had worked briefly with Ernesto Blanco, a professor involved in medical device design and medical patent litigation. She remembered what she liked about medical devices, which was that they "were going to make a very big difference in individual people's lives."

She was still pondering the idea of a career change when she talked to a surgeon friend about her situation. The friend invited her to come to Massachusetts General Hospital to watch some surgeries involving experimental medical devices.

She observed the test of a new device, an aortic stent that could be inserted through the blood vessels like a catheter. The attempt failed, and the surgeons had to revert to traditional open-heart surgery. But that failure was a revelation to Mohr.

"It seemed to me that if the engineers had been as intimately familiar with the body as the surgeons were, there would have been a better chance that the stent would have worked," Mohr says. She listened to the engineers and the surgeons in the operating room. "They just didn't speak each others' languages," she says, noting that the surgeons would propose fantastical solutions that involved breaking the laws of physics, and the engineers would try to bring those solutions into the realm of reality without fully understanding the fundamental problem the device was meant to solve.

Mohr realized that if she wanted to design really revolutionary medical devices, she needed a better understanding of the environment in which they would be deployed—the human body. The best way to get that understanding, she thought, would be to go to medical school.

"Oh, my," was her next thought. "Am I really going to do *that*?"

Mohr looked into academic alternatives—"anything but medical school," as she puts it. But she became convinced that attending a medical school with a surgical program that let her participate in operations was the only way she could get the deep understanding of the human body that she sought.

Everyone she knew thought she was nuts. The typical reaction went like this: "You're throwing away a good income in a high position in a world-famous company that makes great things—to go to medical school?"

But Mohr never saw her choice as throwing anything away. "I always looked at it as adding on. I fully intended to take what I enjoyed at AeroVironment, which is the engineering, and to look at device design from the point of view of someone who's both an engineer and a doctor."

She entered Stanford School of Medicine as a five-year medical student (the extra year is devoted to a research project). While studying to be a doctor she had a child, served on the board of the Association of Women Surgeons, worked

Catherine Mohr

IEEE Member

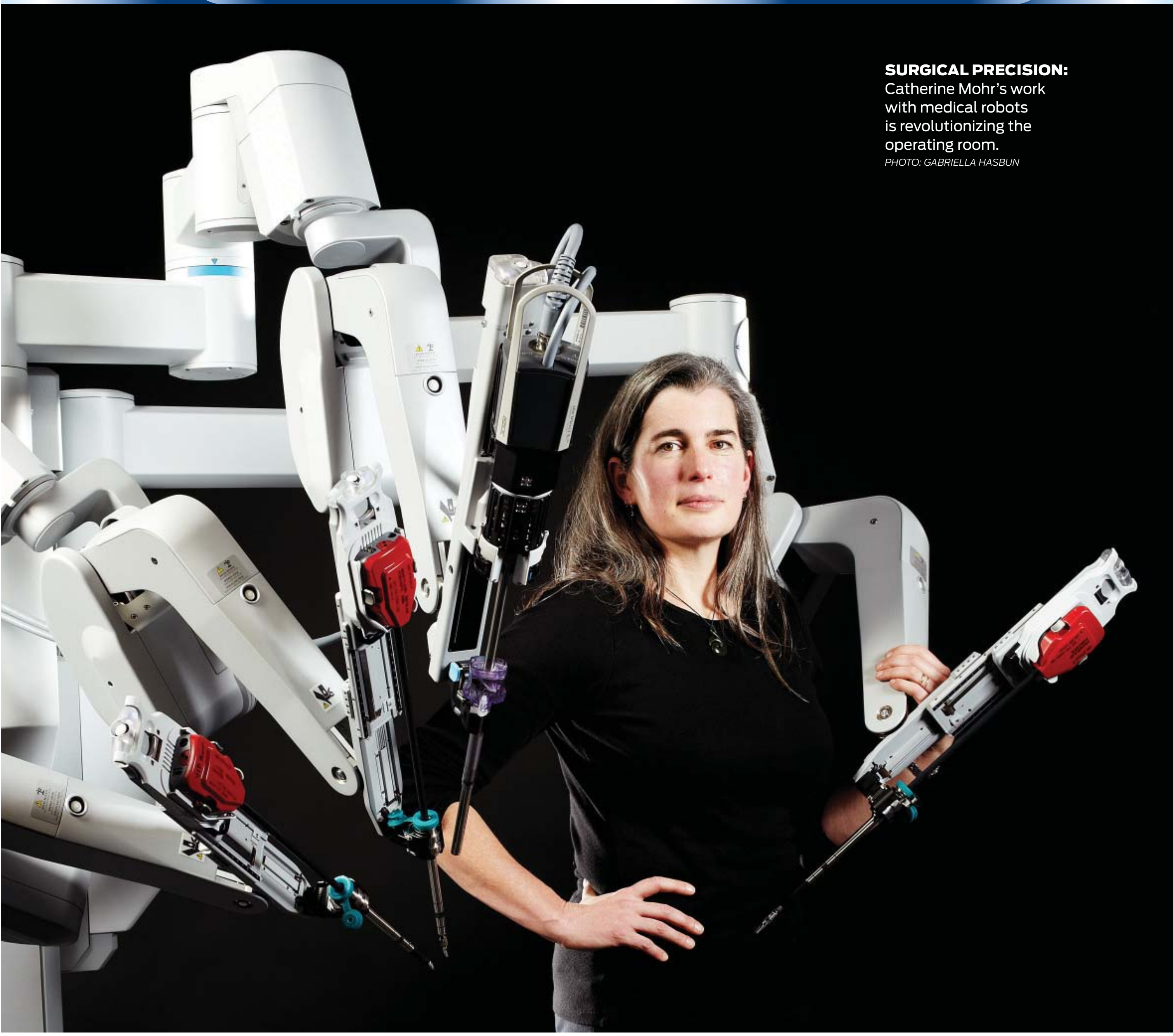
AGE 41

WHAT SHE DOES
Develops advanced tools and procedures for da Vinci surgical robots, helping to make surgery safer and less invasive.

FOR WHOM
Intuitive Surgical

WHERE SHE DOES IT
Sunnyvale, Calif.

FUN FACTORS
Works on projects that involve both engineering and surgery, two of her passions.



SURGICAL PRECISION: Catherine Mohr's work with medical robots is revolutionizing the operating room.
PHOTO: GABRIELLA HASBUN

with the Association of Surgical Education, and spent every free moment trolling the hospital for surgeons who would let her scrub in on operations. She became a regular surgical assistant to two surgeons who specialized in laparoscopies, which are surgical procedures performed through a small incision with the help of a camera. She also developed a tool that makes it safer to inflate the abdomen before laparoscopic surgery and then started a medical device company to market the tool.

And then it came time to sign up for "the match," the annual process by which medical students around the country are assigned to hospitals for internships and residencies.

Mohr didn't register. She loved the intellectual challenge of medicine and the connection with patients. But she loved the design projects she'd been doing on the side just as much. And she had a 2-year-old daughter she needed time for as well. She realized she couldn't do it all.

So she joined Intuitive Surgical, a company located just kilometers from Stanford. Intuitive makes a surgical robot called the da Vinci. She started out by studying the forces generated during surgery by cutting and suturing and is now applying lower-force alternatives to surgery, such as lasers. As director of medical research, she's also investigating applications for other new surgical technologies. One is focal therapy, which involves inserting a catheter into a tumor and then destroying the tumor from the inside out by applying RF, microwave, or other forms of energy. She considers how to integrate such novel techniques into the da Vinci and future surgical robots.

And Mohr gives advice to other engineers who are thinking about going to medical school. "I say it's a long, hard path, and it's fraught with lots of really hard decisions to make along the way about whether you're going to go all the way through residency, if you're going to practice, if you're not. I also tell them that you're probably not going to make a lot of money designing biomedical devices. But it has the potential for being very, very rewarding.

"The job is technical, clinical, and creative, and constantly on the steep part of the learning curve," she says. "It has all the satisfaction of being a researcher in academia, but because I'm in industry, when I find things that will make a very big difference in patients' lives, there's a very short path to getting them into patients."

—Tekla S. Perry

ARCHITECTURE

GREEN-BUILDING GURU

He works with architects to design sustainable buildings

HENRIK SØRENSEN WAS 25 YEARS old when a career counselor asked him to describe his dream job to a room full of unemployed engineers. "To work in solar energy on the southern part of Fyn," Sørensen replied, referring to the Danish island where his father was born.

His response was held up as an example of how not to think about jobs—he was far too specific and inflexible. Sørensen was offended, but he didn't change his answer.

Nineteen years later, on a crisp August afternoon, he sits sipping cappuccino at an outdoor café overlooking a canal in Århus, Denmark, not terribly far from Fyn. Since the rocky beginning of his career as an energy consultant to architects, he's completed about 200 solar-design projects. He credits his devotion to his original dream for keeping him from straying down a less satisfying path.

It wasn't always easy. As a jobless young graduate, he focused on the things that made him feel like an engineer. After his wife left for work each day, he'd get busy checking for openings at the companies he liked. But the months of inactivity wore him down. "After Kirstin went to work in the morning, I managed to read the newspaper," he recalls. "On good days, I managed also to get dressed. I was completely going to zero."

It was a paralyzing state for an engineer who'd known he wanted to pursue a career in solar energy since the seventh grade, when he asked for a book on renewable energy for his birthday. "It was hard to read," he recalls, "but I learned we could melt metal with the rays of the sun—wow!" He grew up with vivid memories of Denmark's empty, carless roads on Sundays, when gasoline was rationed during the oil crisis of 1973. The idea of harnessing the seemingly boundless potential of solar energy to end such threats of scarcity had a profound effect on him.

At the Technical University of Denmark, in Copenhagen, he studied energy engineering and worked at Risø DTU, Denmark's national laboratory for sustainable energy, where he analyzed the role of Norwegian hydroelectricity in the Danish grid. Even seemingly unrelated pursuits fed his curiosity about renewable energy. With a 30-day loan and a purchase of 20 kilograms of coffee beans, he and another student opened a café on campus, in a building where introductory lectures were held. It was the perfect place for snagging sleepy customers. Selling their coffee for one krone per cup (about US $0.20), they made approximately $13 000 and spent the surplus on student bus tours to power plants and wind turbines. Then he graduated in 1992, discovered that there were no solar-related jobs, and saw his busy lifestyle come to a sudden halt.

After he'd been unemployed for four months, his wife pushed him to find a hobby. Sørensen left home to attend a sports school in Oure, on the southern end of Fyn. He bought a boat and took up sailing. He relaxed. "I learned, hey, I can spend a whole day doing other things than being an engineer, crunching numbers, or reading funny stuff about solar collectors, and still feel I spent my time in a good way," he says. The plan was to stay six months, but two weeks later he got his first job offer.

He started working for Esbensen Consulting Engineers, which helps architecture firms plan the engineering behind sustainable buildings, and he's been there ever since. His first assignment turned out to be one of the most important in his career. It was to design a building called the Brundtland Centre, in Toftlund, Denmark, so that it would use half as much energy as similar commercial buildings.

Henrik Sørensen

IEEE Member

AGE 44

WHAT HE DOES
Helps architects engineer low-energy buildings.

FOR WHOM
Esbensen Consulting Engineers

WHERE HE DOES IT
All over Denmark

FUN FACTORS
Collaborates with some of Europe's best designers to usher in the next generation of sustainable architecture.

MASTER PLANNER: Henrik Sørensen engineers better buildings from his main office in Copenhagen. PHOTO: ULRIK JANTZEN

To meet the challenge, Sørensen helped his clients select the building's form, orientation, and materials to push daylight as far into a room as possible. For the windows, he and his partners chose reflective blinds that automatically tilt to let daylight in and reduce glare. They programmed the artificial lighting to adjust itself in response to varying levels of natural light. Movement sensors activate ventilation fans only when occupants appear. Photovoltaic panels laminated onto double-paned glass on an atrium roof generate electricity; heat from solar collectors built into the facade warms fresh air in the atrium before fans circulate it.

Because this was one of Denmark's first comprehensive sustainable design projects, there were few clear answers on how to go about it. For example, Sørensen's collaborators had initially assumed they would include a panel of knobs and switches to control the blinds, lighting, and air circulation. Sørensen was strongly opposed. "Nobody—well, except maybe engineers—wants to live in a building where you need to be a pilot to operate and control things," he says. He talked them down to just a simple +/– button that adjusts the amount of light in a room.

Those fruitful collaborations make the stress of juggling multiple projects and spending late nights at the office worthwhile for Sørensen. When he does work late, the perfect scenario involves meeting up with architects in the evening, after the phones have died down and everyone else has gone home. They surround themselves with tables piled high with sketch paper. "We listen to crazy music and do crazy things, and that's how I try to push our ideas forward," he says. Once they gathered on the roof of an architecture firm, the lights of Denmark's tidy streets twinkling below them, to peer over the edge and see what might happen if they were extremely literal about looking for the "big picture." On another occasion, Sørensen prodded an unfamiliar group of designers to stand up and "dance their lunch." They shuffled around awkwardly before he let them sit down and get back to their sandwiches, hoping they got the point about unconventional thinking.

Now, seated at that café table by the water, he's thinking about his latest preoccupation. Students zip by on bicycles, and parents push strollers across the stone-paved streets. He looks past them toward a set of tall, narrow glass windows running up the side of a century-old, mustard-colored building. Next to it stands a building with a weathered facade and distinctive brown trim. Both buildings are lovely, and also unlike anything else as far as the eye can see. It's that architectural uniqueness that makes energy-efficiency retrofits so challenging.

So he's devising a system that he calls the Lego blocks of sustainable design—a set of rules that would turn nearly any building, regardless of age, size, or structure, into an energy-efficient and comfortable dwelling. Architects, for example, would be directed toward materials that work well together, letting designers expend less effort in creating a house that consumes little energy and more time dreaming up an enjoyable dwelling.

Guided by the pleasing simplicity of those Danish plastic building blocks, Sørensen is making his mark, one building at a time. —Sandra Upson

TOP OF THE WORLD, MA: José Losada stands in front of the world's biggest telescope.
PHOTO: ANA NANCE

PARADISE

ISLAND DREAMS

He writes code for the world's biggest telescope while cavorting in the Canaries

ASTRONOMY'S GOLDEN AGE, most astronomers will tell you, is right now. Four centuries after Galileo pointed his telescope skyward, that primordial instrument's fabulously complicated descendants are giving researchers stunning insights into black holes, the birth of galaxies, even the nature of physics itself. The whole enterprise depends on observatories that cost as much as atom smashers—and need about the same amount of automation.

Providing that automation is a huge challenge. It can also be a blast, if you get to do it for a cutting-edge instrument that happens to be in the gorgeous Canary Islands, as José Losada does. As a senior computer scientist in charge of major systems at the Gran Telescopio Canarias, Losada, 42, writes the code that controls the instrument with the largest light-collecting mirror in the world.

Tenerife, the most populous of the Canary Islands, has the most in the way of people, nightlife, and culture, and it's on Tenerife where Losada gets to live. But the telescope is on a lofty mountain on the island of La Palma, a half-hour flight away. When *IEEE Spectrum* visited in June, Losada was subbing for his boss, who

José Losada

IEEE Member

AGE 42

WHAT HE DOES
Works on the software that runs the biggest telescope on Earth.

FOR WHOM
Gran Telescopio Canarias

WHERE HE DOES IT
Tenerife and La Palma, in Spain's Canary Islands

FUN FACTORS
Works amid sunshine, surf, subtropical weather, and wild canaries.

was out on sick leave, by supervising 10 people. One or two of them rotate through the observatory on La Palma, but they all live on Tenerife, too.

"This is a good balance," Losada says. "Live here, work there—when you need to install something, you go there to do it." What he installs is software.

His is a laid-back, small-town world, with a tight circle of friends. At a café in Santa Cruz de Tenerife, the bustling little capital, he encounters several friends from past classes in tai chi and contemporary dance, his greatest passion.

"If I could live life over," Losada sighs, "I'd be a dancer." His troupe recently performed in the Audiotorio, a swoopy bird of a building perched on the bay of Santa Cruz. Losada missed that one because he was traveling on telescope business.

We fly to La Palma and find the Gran Telescopio to be worthy of its name. It crouches like an idol in its silvered dome, atop an exhausted volcano, where the air is so dry that it chaps your lips in a few hours. The telescope's primary, light-collecting mirror, measuring 10.4 meters, is the largest in the world. In its particular sliver of spectrum, the infrared, the Gran peers farther away and thus further back in time than any other such telescope has done, surveying the birth of stars and the tug of black holes—the face of the universe when it was young.

Losada and his colleagues had to write millions of lines of code to manipulate the telescope and its supporting apparatus. First, there's the primary mirror, made of 36 hexagonal glass segments, each one propped and prodded by actuators that keep its shape constant no matter how it's positioned. It's called active control, and it's also applied to the secondary mirror, a plate of beryllium metal that redirects the beam to detectors at several focal points.

"The main thing is efficiency," Losada explains. "You can manage complex observations in a short period and change the instrumentation depending on weather conditions. If the quality of the sky is not good enough, you can do a different observation quickly."

We're talking about writing software from scratch for a very particular project—a green field, not a tilled one. It'd be a dream job even without the surf, the sun, and the mountains.

"Only now are we creating a maintenance group," Losada says, "to work during the 50-year life of the telescope. We are trying to find ways to recycle some of the software we developed and trade it with other telescope projects."

Original design, though, is what he relishes. To keep on automating the astronomy business, he's hoping that his group gets to collaborate on the proposed European space telescope.

Right now, he and his colleagues are tying up loose ends. In July, they attended the telescope's formal inauguration in the presence of the king and queen of Spain.

Even a crowned head must wear a hard hat inside the dome, but Losada asked me to take mine off before entering the shop where mirror segments are refurbished. It seems that a journalist once nearly hit his hard hat on one of them. It would have cost a million dollars to fix it, Losada says, with a look of mock horror. It turned to real horror as I pulled back, nearly colliding with another mirror. But he grabbed my hand, and the danger passed.

He is, after all, a master of active control. —Philip E. Ross

AQUATIC

RAPTURE OF THE DEEP

He makes the dive computer that every aquanaut wants

ON ONE OF THE LAST shimmering days of summer, two weathered, middle-aged men undress in a parking lot on the northeastern shore of Lake Zurich. This is the city's Gold Coast, where a halfway decent villa will set you back a couple of million francs. Jabbering in a Swiss dialect while working with swift, sure hands, the divers pull on thick black exposure suits and 20 kilograms of gear, including two big steel cylinders of pressurized breathing gas.

"It's not always fun like this!" says one of the divers, a trim fellow with salt-and-pepper hair and a neatly trimmed beard. That's Ernst Völlm. He lives on the shadier side of the lake. But he loves it here, where as a kid he used to swim, snorkel, and dream of being an underwater explorer like his idol, Jacques Cousteau.

For Völlm, today is a workday. On his left wrist he's wearing his latest creation, an advanced dive computer known, appropriately enough, as the Zurich Scuba Diver Assistant, or SDA. He and his jovial dive buddy, Georges Götte, waddle web-footed down to the water, joking with nearby swimmers. Götte calls out *"Gute Luft"* ("good air"), and they jump in feet first. As Völlm descends into the blue depths, he clutches a rack of SDAs. Twenty minutes later, the divers resurface, and Völlm's rack is chirping like a field of crickets. To test the units, he had "tricked" them into thinking he'd dangerously exceeded safety limits, and they are all screeching in protest.

Völlm is chief technology officer for Underwater Equipment Made in Switzerland, or UEMIS, headquartered in Adliswil. The 5-year-old firm's offering is already among the world's most coveted dive com-

DE PROFUNDIS: Ernst Völlm emerges from the deep with his dive computer on his wrist.
PHOTO: CÉDRIC WIDMER

puters. Like any such unit, the SDA records the diver's depth and time underwater and uses that data to calculate, every few seconds, whether it's safe to return to the surface. If it's not, the computer calculates a decompression schedule—basically an ascent plan that will let the diver get back to the world of air and light without risking a case of decompression sickness, better known as the bends.

Völlm built his first piece of diving gear—a diving lamp ("a car light in a housing, more or less")—when he was 20. At the time he was studying mechanical engineering at the Swiss Federal Institute of Technology. His first job was at a yarn-winding company, where he worked on an electronic bobbin winder.

Meanwhile, he was training to be a diving instructor and helping to establish the Swiss Office for the Prevention of Diving Accidents. Switzerland may be landlocked, but it's a diver's paradise. The country's gin-clear mountain lakes offer trout, distinctive underwater landscapes, and for part of the year, through-the-looking-glass views of surface ice. But the low air pressure at high altitudes complicated the calculations that divers had to do to minimize their risk of the bends. The tediousness and precariousness of the chore got Völlm thinking about how microprocessors could do it better.

In 1987, Völlm and Markus Mock, an engineer friend, founded their own company, Dynatron, and designed the hardware and software for a dive computer that was manufactured and marketed by Uwatec, a diving equipment maker based in Hallwil, Switzerland. That first computer did well, selling upward of 100 000 units all over the world. Other models followed, including a type known as a console unit: A high-pressure hose attached it to the diver's air tank so that he could see, in one place and in real time, all the critical information related to the dive—his depth, total time underwater, how much longer he could stay down without risking a case of the bends, the temperature, and most important, the tank's pressure.

It was the beginning of a 17-year relationship with Uwatec that ended in 2004, seven years after the firm was bought out by the American firm Johnson Outdoors. Sometime later, another of Völlm's diving buddies, Lukas Metzler, got Völlm and Mock to join him in starting a company to create a state-of-the-art dive computer. It would be worn on the diver's wrist and get pressure readings from the tank via a wireless link. But whereas other computers allow the diver to see only his own data, Völlm and Mock's would be part of an ad hoc network. Instead of swimming to your dive buddy to read how much air he had left, you could check it on your own unit. The computer would also interface with the Internet via a PC hookup to upgrade software or synchronize log data with a Web-based logbook, for example.

They tested their first two prototypes in January 2008 in Lake Zurich, in witheringly frigid water. Völlm and Metzler, now the company's CEO, each went under with one of the gadgets, only to have the prototypes' plastic casing crack from the cold. "But they were still watertight, and we could make the tests," Völlm recalls proudly. Many other test dives followed. With its organic-LED display, the current-generation SDA is a marvel of diving technology, with a price tag to match: US $1600, or €1120. It stores details on up to 2000 past dives and also allows multiple divers to communicate underwater.

The units arrive at UEMIS semifinished from a factory elsewhere in Switzerland. Technicians check pressure resistance and function by exposing the SDAs to a simulated saltwater environment. The ruggedness test is simple but effective—they'll occasionally throw one down a flight of stairs.

As CTO of UEMIS, Völlm describes his job as "everything except maybe the finances." Lately, he's been globe-hopping to promote the product. The company has seven full-time employees; Völlm insists that they all pass a basic diving course so that they'll better understand the product they make. Anyone with a technical and scientific bent can't help but be intrigued by dive computers, Völlm says, because the design and operation of these tiny but powerful computers pulls together so many fascinating disciplines: medicine and physiology, electronics, software and modeling, mechanics, and physics.

When Völlm was in industry, he knew he wanted more responsibility—and especially more risk. As an entrepreneur, he's found it. There are times when he feels a bit overwhelmed by the responsibilities, he concedes. But that's when he can go back to the place that fueled his dreams as a boy—where he can pull on a thick diving suit and remind himself how much fun it can be to *really* be in over your head. —GISELLE WEISS

Ernst Völlm

AGE 54

WHAT HE DOES
Designs the world's most advanced dive computers.

FOR WHOM
Underwater Equipment Made in Switzerland (UEMIS)

WHERE HE DOES IT
Adliswil, Switzerland

FUN FACTORS Goes diving almost every week, often in Lake Zurich; travels to diving trade shows all over the world.

VICE OVER IP

A growing cadre of criminals is hiding secret messages in voice data

By JÓZEF LUBACZ, WOJCIECH MAZURCZYK & KRZYSZTOF SZCZYPIORSKI

MICK WIGGINS

7:00 P.M., SHANGHAI

An employee of an electronic equipment factory uploads a music file to an online file-sharing site. Hidden in the MP3 file (Michael Jackson's album *Thriller*) are schematics of a new mobile phone that will carry the brand of a large American company. Once the employee's Taiwanese collaborators download the file, they start manufacturing counterfeit mobile phones essentially identical to the original—even before the American company can get its version into stores.

3:30 P.M., SOMEWHERE IN AFGHANISTAN

A terrorist hunted by the U.S. Federal Bureau of Investigation posts an excerpt from the motion picture *High School Musical Three: Senior Year* on Facebook. Inside are hidden instructions for a bomb attack on a commuter rail line in southern Europe. Later that day, terrorists based in Athens follow the instructions to plan a rush hour attack that kills hundreds of people.

4:00 A.M., MALIBU, CALIF.

A very famous actor (VFA) has a brief conversation with a well-known director (WKD) over Skype, an application that lets them make free voice calls over the Internet. They discuss the medical problems of VFA's cat in great detail. When the conversation is over, WKD's computer has a sleazy new addition—in a folder on his desktop, there is a picture of a nude teenager, along with her mobile number and the date and time at which WKD will meet her at VFA's pool party for a photo session.

WHAT ALL these scenarios have in common is an information-smuggling technique called steganography—the communication of secret messages inside a perfectly innocent carrier. Think of steganography as meta-encryption: While encryption protects messages from being read by unauthorized parties, steganography lets the sender conceal the fact that he has even sent a message. After the 11 September attacks in 2001, rumors flew that they had been carried out with some help from steganography. A 2001 *New York Times* article described fake eBay listings in which routinely altered pictures of a sewing machine contained malevolent cargo. The link to 9/11 was never proved or disproved, but after those reports, the interest in steganographic techniques and their detection greatly increased.

Steganography use is on the rise, and not just among criminals, hackers, child pornographers, and terrorists. Persecuted citizens and dissidents under authoritarian regimes use it to evade government censorship, and journalists can use it to conceal sources. Investigators even use it on occasion to bait and trap people involved in industrial espionage: In the 1980s, to trace press leaks of cabinet documents, British Prime Minister Margaret Thatcher had government word processors altered to encode a specific user identity in the spaces between words. When leaked material was recovered, the identity of the leaker could be established by analyzing the pattern of those spaces.

Steganography is evolving alongside technology. A few years ago the cutting edge in steganographic tools involved hiding messages inside digital images or sound files, known as carriers, like that *Thriller* MP3. The technique quickly evolved to include video files, which are relatively large and can therefore conceal longer messages.

Now steganography has entered a new era, with stupendously greater potential for mischief. With the latest techniques, the limitations on the length of the message have basically been removed. Consider our example involving the use of Skype. Whereas the first two examples each required a carrier—an MP3 song and a video—there was no such requirement for the transmission of that nude photo. The data were secreted among the bits of a digital Voice over Internet Protocol conversation. In this new era of steganography, the mule that coconspirators are using is not the carrier itself but the communication protocols that govern the carrier's path through the Internet. Here's the advantage: The longer the communicators talk, the longer the secret message (or more detailed the secret image) they can send. Most strikingly, the concealment occurs within data whose inherent ephemerality makes the hidden payload nearly impossible to detect, let alone thwart.

We call this new technique network steganography. In our research at the Network Security Group at Warsaw University of Technology, we are studying the ever-evolving spectrum of carrier technologies, the increasing difficulty of detection as more sophisticated carriers leave fewer traces, and the implications of both for law enforcement and homeland security. Our work at Warsaw is literally self-defeating: We figure out the most advanced ways of doing network steganography and then design methods to detect them.

NETWORK STEGANOGRAPHY is a modern version of an old idea. You could argue that steganography helped spark the first major conflict between Greece and the Persian Empire. A classic use of steganography took place in 494 B.C., when Histiaeus, the ruler of Miletus, tried to instigate an Ionian revolt against the Persians. He shaved his favorite slave's head, tattooed it with a message, and waited for the slave's hair to grow back and obscure the tattoo. Then he sent the slave to his destination, where the intended recipient shaved the slave's head and read the message. The ensuing Ionian revolution lasted for half a century. In the 19th and 20th centuries, rapidly evolving warfare and espionage brought many innovations in steganography: Invisible ink, microdots, and Thatcher's word-processor trick are only a few among many.

With today's technology, information can be smuggled in essentially any type of digital file, including JPEGs or bitmaps, MP3s or WAV files, and MPEG movies. More than a hundred such steganographic applications are freely available on the Internet. Many of these programs are slick packages whose use requires no significant technical skills whatsoever. Typically, one mouse click selects the carrier, a second selects the secret information to be sent, and a third sends the message and its secret cargo. All the recipient needs is the same program the sender used; it typically extracts the hidden information within seconds.

CARRIER EVOLUTION

Steganography has been used for at least 2500 years to disguise secret messages. In its earliest forms, the carriers were physical, but as technology evolved, so did carriers.

494 B.C.
HEAD TATTOO

Histiaeus tattoos a secret message onto a slave's shaved head, waits for the hair to regrow, and sends the slave to the intended recipient, who shaves off the hair to read the message.

480 B.C.
BEESWAX

Demaratus writes a secret message on a wooden tablet to warn the Greeks of Persian attack, and then covers it with many coats of wax.

1558
EGGS

Italian scientist Giambattista della Porta discovers how to hide a message inside a hard-boiled egg: Write on the shell using an ink made from a mixture of alum and vinegar. The solution leaves no trace on the surface,

ANOUCHKA/ISTOCKPHOTO

A SINGLE 6-MINUTE MP3 OCCUPIES 30 MB, ENOUGH TO CONCEAL EVERY PLAY SHAKESPEARE EVER WROTE

Any binary file can be concealed—for instance, pictures in unusual formats, software (a nasty virus, say), or blueprints. The favored carrier files are the most common ones, like JPEGs or MP3s. This emphasis on popular file formats increases the anonymity of the entire transaction, because these file types are so commonplace that they don't stick out.

The one limitation that steganographers have traditionally faced is file size. The rule of thumb is that you can use 10 percent of a carrier file's size to smuggle data. For an ambitious steganographer, that could be a problem: Imagine an electronic equipment factory employee trying to explain to the IT department why he has to send his mother a 100-megabyte picture of the family dog. For that reason, steganographers soon turned to audio and video files. A single 6-minute song, in the MP3 compression format, occupies 30 MB; it's enough to conceal every play Shakespeare ever wrote.

And yet, even with these precautions, conventional steganography still has an Achilles' heel: It leaves a trail. Pictures and other e-mail attachments stored on a company's outgoing e-mail servers retain the offending document. Anything sent has to bounce through some kind of relay and can therefore be captured, in theory.

Steganography poses serious threats to network security mainly by enabling confidential information leakage. The new crop of programs leaves almost no trail. Because they do not hide information inside digital files, instead using the protocol itself, detecting their existence is nearly impossible.

ALL THE new methods manipulate the Internet Protocol (IP), which is a fundamental part of any communication, voice or text based, that takes place on the Internet. The IP specifies how information travels through a network. Like postal service address standards, IP is mainly in charge of making sure that sender and destination addresses are valid, that parcels reach their destinations, and that those parcels conform to certain guidelines. (You can't send e-mail to an Internet address that does not use a 32-bit or 128-bit number, for example.)

All traffic, be it e-mail or streaming video, travels via a method called packet switching, which parcels out digital data into small chunks, or packets, and sends them over a network shared by countless users. IP also contains the standards for packaging those packets.

Let's say you're sending an e-mail. After you hit the Send button, the packets travel easily through the network, from router to router, to the recipient's in-box. Once these packets reach the recipient, they are reconstituted into the full e-mail.

The important thing is that the packets don't need to reach their destination in any particular order. IP is a "connectionless protocol," which means that one node is free to send packets to another without setting up a prior connection, or circuit. This is a departure from previous methods, such as making a phone call in a public switched telephone network, which first requires synchronization between the two communicating nodes to set up a dedicated and exclusive circuit. Within reason, it doesn't matter when packets arrive or whether they arrive in order.

As you can imagine, this method works better for order-insensitive data like e-mail and static Web pages than it does for voice and video data. Whereas the quality of an e-mail message is immune to traffic obstructions, a network delay of even 20 milliseconds can very much degrade a second or two of video.

To cope with this challenge, network specialists came up with the Voice over Internet Protocol (VoIP). It governs the way voice data is broken up for transmission the same way IP manages messages that are less time sensitive. VoIP enables data packets representing a voice call to be split up and routed over the Internet.

The connection of a VoIP call consists of two phases: the signaling phase, followed by the voice-transport phase. The first phase establishes how the call will be encoded between the sending and receiving computers. During the second phase, data are sent in both directions in streams of packets. Each packet, which covers about 20 milliseconds of conversation, usually contains 20 to 160 bytes of voice data. The connection typically conveys between 20 and 50 such packets per second.

Telephone calls must occur in real time, and significant data delays would make for an awkward conversation. So to ferry a telephone call over the Internet, which was not originally intended for voice communications, VoIP makes use of two more communications protocols, which had to be layered on top of IP: The Real-Time Transport Protocol (RTP) and the User Datagram Protocol (UDP). The RTP gets time-sensitive video and audio data to its destination fast and so has been heavily adopted in much of streaming media, such as telephony, video teleconference applications, and Web-based push-to-talk features. To do that, it relies in turn on the UDP.

Because voice traffic is so time critical, UDP does not bother to check whether the data are reliable, intact, or even in order. So in a VoIP call, packets are sometimes stuck in out

but the message is retrieved by removing the shell and reading the egg.

1800s

NEWSPAPER CODE

During the Victorian era, lovers send secret letters by punching holes above certain letters. When the marked letters are combined, the message can be read.

1915

INVISIBLE INK

During World War I, entertainer and German spy Courtney de Rysbach performs in shows all over Britain as a cover for gathering information. Using invisible ink, Rysbach encodes secret messages by writing them in invisible ink on sheets of music.

1941

MICRODOTS

During World War II, German agents photographically shrink a page of text down to a 1-millimeter dot. The microdot is then hidden on top of a period in an otherwise unremarkable letter.

ALL THREE STEGANOGRAPHIC IDEAS WE'VE OUTLINED HERE ARE SO SIMPLE, WE'RE CERTAIN THAT REAL-LIFE APPLICATIONS ARE ALREADY OUT THERE

of sequence. But that's not a big deal because the occasional misplaced packet won't significantly affect the quality of the phone call. The upshot of UDP is that the protocol opens a direct connection between computers with no mediation, harking back to the era of circuit switching: Applications can send data packets to other computers on a connection without previously setting up any special transmission channels or data paths. That means it's completely private.

Compared to old-fashioned telephony, IP is unreliable. That unreliability may result in several classes of error, including data corruption and lost data packets. Steganography exploits those errors.

Because these secret data packets, or "steganograms," are interspersed among many IP packets and don't linger anywhere except in the recipient's computer, there is no easy way for an investigator—who could download a suspect image or analyze an audio file at his convenience—to detect them.

To better understand what security officials will soon have to deal with, we designed and developed three flavors of network steganography, all of which manipulate IP. The three methods we developed are Lost Audio Packet Steganography, or LACK; Hidden Communication System for Corrupted Networks (HICCUPS); and Protocol Steganography for VoIP application. As their names imply, these techniques exploit lost packets, corrupted packets, and hidden or unused data fields in the VoIP transmission protocol. LACK hides information in packet delays, HICCUPS disguises information as natural "distortion" or noise, and Protocol Steganography hides information in unused data fields.

In regular VoIP telephony, excessively delayed packets containing voice samples are considered useless by the receiver and thus discarded. LACK exploits this mechanism to transmit hidden data. Some of the sender's packets are intentionally delayed, and the steganograms are stowed away inside those delayed packets. To any node that is not "in the know"—that is, a nearby computer that does not have the steganography program installed—they appear useless and are ignored. But if the receiver has the proper software to understand the steganography, it will not discard the excessively delayed packets. It will know that these contain the hidden data [see diagram, "Hidden in the Network"].

The transmission capacity for this scheme depends on the system used to encode the voice and on the quality of the network—specifically, how well it handles packet loss and delays. Using a standard 32-bit-per-second codec, and accounting for a 3 percent packet loss introduced by the network and a 0.5 percent packet loss introduced by LACK itself, a smuggler could transmit about 160 bits per second. At that rate you might be able to transmit a medium-size, 13-kilobyte image or a 2000-word text file during a typical 9- to 13-minute VoIP conversation.

LACK's main selling points are that it is simple to use and hard to detect. The only way it could be detected is if the user tried to hide too many secret packets. In that case, the number of intentionally delayed packets—and therefore the introduced delay—would create a suspiciously abnormal voice connection that might attract the attention of any security officials monitoring the line. If the call was completed before those officials could intercept the packets, however, there would be nothing they could do to try to uncover and assemble the steganograms.

Where LACK relies on lost packets to smuggle steganograms, HICCUPS takes advantage of corrupted packets. HICCUPS is fast. Let's say you have an IEEE 802.11g network with a transmission capacity of 54 megabits per second, with 10 terminals and a 5 percent rate of corrupted frames. Over such a network, you could send hidden data at a rate higher than 200 kilobits per second. That's almost as fast as the ISDN lines that were all the rage in the 1990s.

HICCUPS works on wireless local area networks, such as plain old coffee shop Wi-Fi. In such a wireless environment, data are transmitted by a method called broadcasting, which shuttles data in groups called frames. Like many courier services, broadcasting doesn't concern itself with the contents of the data or whether the data contain errors. When a wireless network detects an error in a frame, the computer simply drops that corrupted frame. The responsibility for detecting dropped frames (and retransmitting them if necessary) is left to the origin and destination terminals.

So in a wireless local-area network, all the user terminals (laptops, for the most part) must have a way of differentiating good packets from corrupted ones. This error-checking mechanism is called the checksum, a kind of signature against which the integrity of the packets can be confirmed. The checksum is a numerical value assigned to a data packet based on the number of bits in that packet. A checksum program uses that value to authenticate that the data hasn't been corrupted.

When the receiver's computer gets a packet, it checks for errors using that packet's checksum. Normally, if the checksum is wrong, the computer discards that packet. But if a terminal has

1980s
WATERMARKING

In the 1980s, to trace press leaks of cabinet documents, British Prime Minister Margaret Thatcher has government word processors altered to encode a specific user identity in the spaces between words.

1990s
DIGITAL STEGANOGRAPHY

Researchers develop methods to secretly embed a signature in digital pictures and audio, exploiting the human visual system's varying sensitivity to contrast.

2003
STREAMING VIDEO

Video steganography is similar to image steganography, but more information may be transported in a stream of images.

2007
NETWORK STEGANOGRAPHY

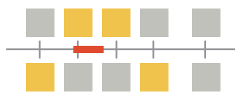
New methods focus on using free or unused fields in a protocol's headers.

AP PHOTO

HIDDEN IN THE NETWORK

HICCUPS
(CORRUPTED PACKETS)

Hides in normal corruption

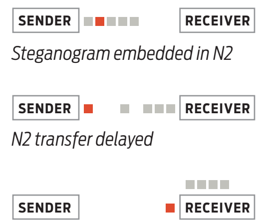


Highest information density HICCUPS [red] hides in the "noise" of natural distortion [orange] in an otherwise normal VoIP telephone call [gray].

Difficult to use Because this method requires hardware that can generate wrong checksums, it is difficult to use.

200 kilobits per second are transmitted during a typical 9–13 minute VoIP call.

LACK
(LOST AUDIO PACKETS)

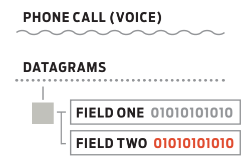


Lowest information density Excessively delayed packets are dropped by the receiver. LACK delays packets on purpose, encodes the hidden data, and decodes the steganograms when they arrive.

Hardest to detect Used carefully, LACK delays only a small percentage of packets.

160 bits per second are transmitted during a typical call.

PROTOCOL STEGANOGRAPHY
(HIDDEN FIELDS)



VoIP breaks voice data into datagram packets. Each packet contains frequently changing fields, such as authentication.

Easiest to use Each bit (phone-call data) contains data fields. Some fields contain frequently changing data, which can be wholly or partially replaced with a steganogram.

Hard to detect By replacing the authentication field, the user sacrifices security.

1–300 bits per second are transmitted during a typical call.

the right steganography program installed, it won't discard these intentionally wrong checksums—instead, it will know that these are precisely the data packets to scan for steganograms.

HICCUPS is more difficult to pull off than LACK. That's because this method requires a wireless card that can control frame checksums (good luck finding one of those at RadioShack). Network cards create checksums at the hardware level. We have applied for a patent in Poland for a HICCUPS-enabled card that can control checksums, but so far we haven't built our own card. Detecting HICCUPS wouldn't be easy. You'd need some way of observing the number of frames with incorrect checksums. If the number of those frames is statistically anomalous, then you might suspect the transmission of hidden information. Another way of detecting HICCUPS would analyze the content of those dropped—and therefore retransmitted—frames in order to detect the differences between the dropped and retransmitted frames. Major differences in these frames would constitute an obvious clue to nefarious goings-on.

Any of these detection methods, of course, would require not only that an investigator be aware that a transmission was about to take place but also that he be equipped with the right equipment, ready to monitor the conversation and intercept bits. Such a situation would be unlikely, to put it mildly.

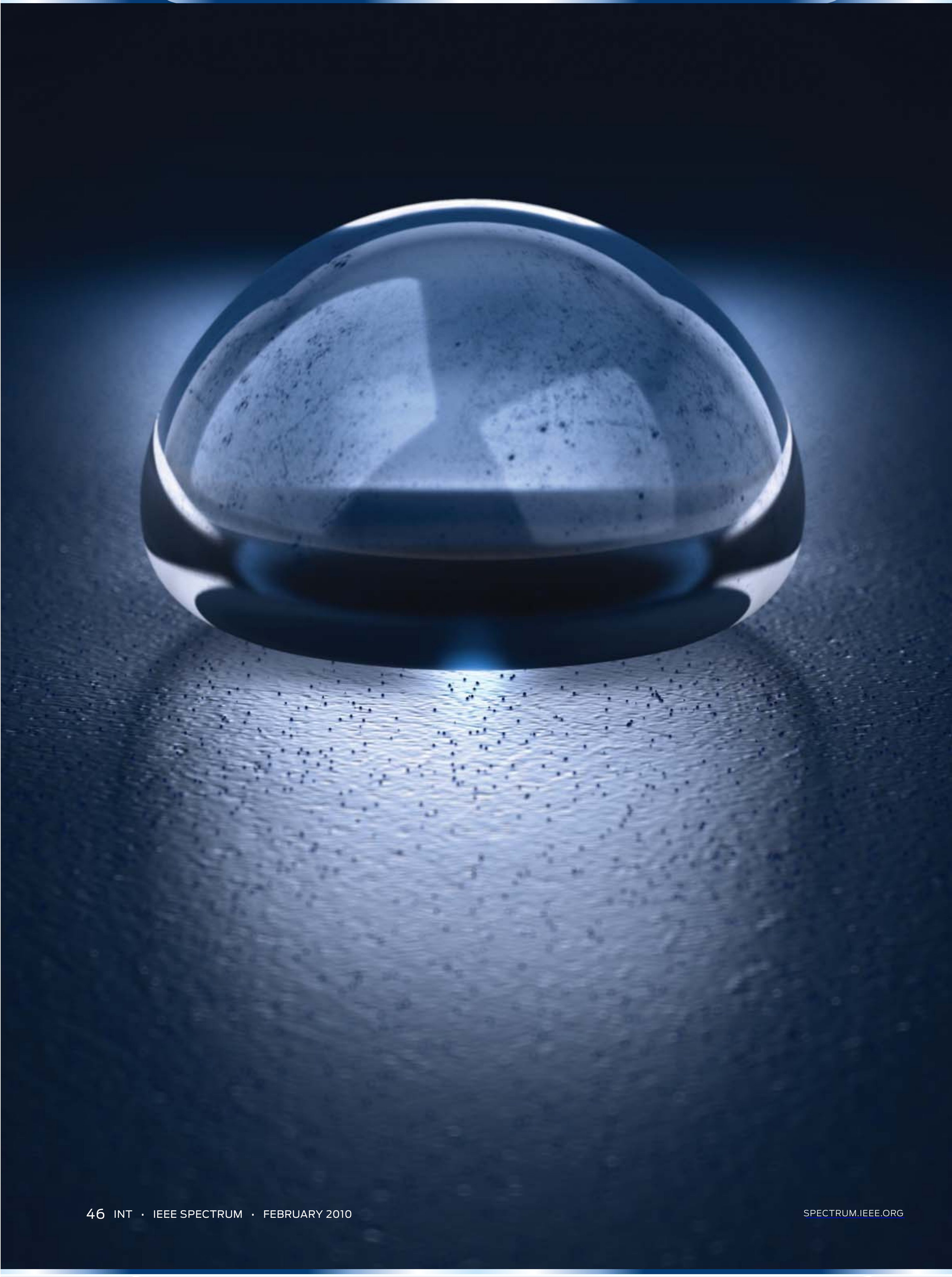
The third method, Protocol Steganography, is a common name for a group of methods that use another aspect of IP: packet header fields. These fields are like sophisticated address labels that identify the contents of data packets to the recipient. Steganograms can be hidden inside unused, optional, or partial fields, because any data in these fields can be replaced without affecting the connection. Some of the more ham-fisted steganography techniques simply replace the content of the unused or optional fields with steganograms. But that would be relatively easy to detect and even jam.

So, to evade detection by simple analysis, the more sophisticated variant of Protocol Steganography uses fields in which the content changes frequently. For example, some of the more esoteric VoIP fields carry security data for authentication purposes. That little authentication subfield changes frequently during the course of a normal call. A steganogram smuggled inside one of its many randomly changing packets would be extremely hard to detect. Of course, there is a trade-off: The user would also sacrifice security, meaning that his or her conversation could be intercepted more easily.

Minimizing the threat of evolving steganography methods requires an in-depth understanding of how network protocols function and how they can be exploited to hide data. The problem is, however, the complexity of today's network protocols. All three steganographic ideas we've outlined here are so simple, we're certain that real-life applications are sure to come, if they aren't already out there. In fact, much more sophisticated methods will appear as Internet communication evolves from VoIP to other real-time media communications, such as video chat and conferencing.

THE ANONYMITY OF STEGANOGRAPHY might be good for privacy, but it also multiplies the threats to individuals, societies, and states. The trade-off between the benefits and threats involves many complex ethical, legal, and technological issues. We'll leave them for other thinkers and other articles.

What we're trying to do is understand what kind of potential contemporary communication networks have for enabling steganography, and in effect, create new techniques so that we can figure out how to thwart them. Some readers may object to our detailed descriptions of how these methods can be harnessed. But we would counter that unless someone shows how easy all this is, researchers won't understand the urgency and be inspired to develop protective measures. Not only can VoIP steganography be implemented in telephony tools that require a laptop or PC (like Skype), it can also be used in hard phones, such as the Android VoIP-enabled mobile phones that are starting to proliferate. Steganography on a phone is more difficult, because it requires access to the device's operating system, but no one should doubt that committed individuals will have no trouble rising to the challenge. As George Orwell once wrote, "On the whole human beings want to be good, but not too good, and not quite all the time." ❏



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CONNECTING THE QUANTUM DOTS

Optoelectronic materials that can be applied like paint will yield cheap solar cells

BY EDWARD H. SARGENT

NOT SO LONG AGO, ARTISTS ROUTINELY MADE their own paints using all sorts of odd ingredients: clay, linseed oil, ground-up insects—whatever worked. It was a crude and rather ad hoc process, but the results were used to create some of the greatest paintings in the world.

Today I and other scientists are developing our own special paints. We're not trying to compete with Vermeer or Gauguin, though. We hope to create masterpieces of a more technical nature: optoelectronic components that will make for better photovoltaic cells, imaging sensors, and optical communications equipment. And we're not mixing and matching ingredients quite so haphazardly. Instead, we're using our blossoming understanding of the world of nanomaterials to design the constituents of our paints at the molecular level.

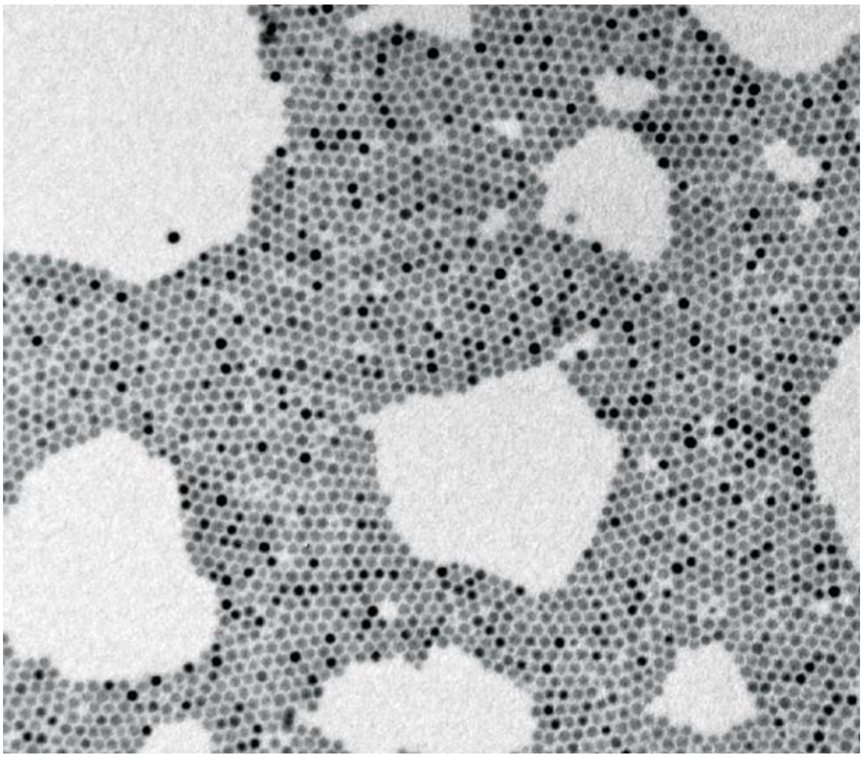
For well over a decade, researchers have been investigating ways to make optoelectronic devices by painting, spraying, or printing the active materials onto an appropriate backing. This work has generated various commercial products, including flexible photovoltaic cells and ultrathin, high-contrast displays, Sony's XEL-1 being a prime example of the latter. The organic polymers from which these devices are built absorb or emit light at visible wavelengths. But making paint-on optoelectronic materials that are sensitive to the infrared—that is, to wavelengths longer than those of visible light—opens up even further possibilities.

Infrared wavelengths are particularly valuable in solar cells. Such a cell must absorb infrared as well as visible light, lest it squander half the sun's energy. And imaging devices that are sensitive to infrared provide a remarkable way to pierce through fog and to view outdoor scenes at night, using the faint infrared glow of the upper atmosphere as illumination. And for optical communications, the equipment must operate in

ILLUSTRATION: JAMES ARCHER/ANATOMY BLUE

the infrared, because outside of certain wavelength bands in this range, glass fibers tend to absorb or distort the light sent through them. Infrared is also useful for conducting secure line-of-sight optical communications.

My colleagues and I at the University of Toronto have made great progress in recent years building devices using what are essentially paints that respond well to infrared wavelengths. This work is still in the research stage—products remain between one and five years away, depending on the application—but the pace of advance has been so swift that it's not too soon to look forward to the many exciting possibilities.



QUANTUM DOTS: This electron-microscope image shows close up the nanometer-scale quantum dots used by the author and his research team to fashion infrared-sensitive optoelectronic devices. *IMAGE: EDWARD H. SARGENT*

YEARLY SALES of photovoltaic panels now amount to tens of billions of dollars, and the overall energy market is measured in the trillions. The ideal that solar-cell developers are seeking is a device that is both efficient and inexpensive. Solar cells constructed from costly semiconductor wafers have yielded the greatest efficiencies—upward of 40 percent—but because they are so difficult to manufacture, such high-efficiency cells are too pricey for all but the most demanding applications, such as for the solar panels attached to spacecraft.

Photovoltaic cells made out of organic polymers cost far less, but the best efficiencies they've shown have typically been around 5 or 6 percent. That's stunningly good for something that can be manufactured so cheaply, but it's still less than the 10 percent figure experts say will be needed for this technology to take off commercially.

One common strategy to boost the efficiency of solar cells of any kind might be called the layer-cake method. The top layer of the cell absorbs photons of relatively short wavelengths, and thus of high energy, turning them into electricity. These wavelengths include visible light and some of the ultraviolet as well. Photons of lower wavelengths pass through this layer into a second one below, which is designed to absorb them and transform their energy into electric power. Some of these layer-cake designs include a third stratum at the bottom to capture the even lower-energy photons that penetrate the top two layers.

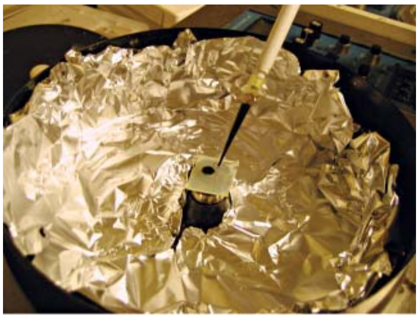
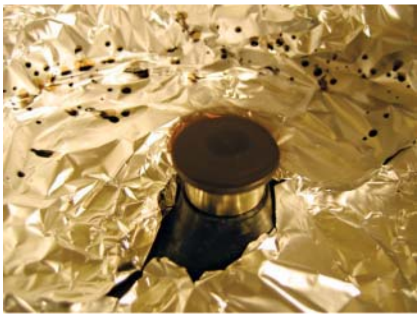
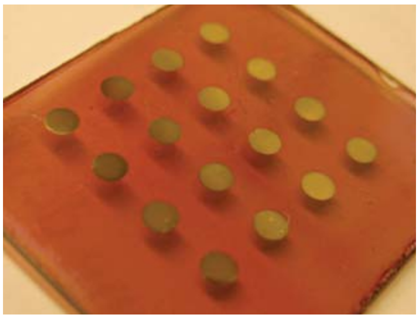
Companies making paint-on or print-on solar cells have been unable to take advantage of this strategy, however. The reason is that for years the only paintable photovoltaic materials have been based on organic molecules that are sensitive to visible wavelengths or to infrared wavelengths that are very close to the red end of the visible spectrum. So manufacturers had nothing that could be used for the lower layers.

Fortunately, the researchers on my team have lately made good progress in devising paint- or print-on solar cells sensitive to infrared wavelengths that are well separated from the visible spectrum, which is to say wavelengths of 1 micrometer or longer. Five years ago, when we first proved the concept, the efficiencies at these wavelengths for our pioneering devices were less than 1 percent. But in 2008 we showed how to boost efficiencies to just under 4 percent. That's only about a third of the efficiency figure you'd need for commercialization, but it represents a huge step forward, and we expect further progress as we continue to devise new and better designs.

Our infrared solar cells contain something called quantum dots—tiny bits of semiconducting materials that absorb or emit light. For our work, we used particles of a lead-sulfur compound. We and others are also experimenting with compounds of bismuth, tin, and indium with sulfur, selenium, and oxygen. Whereas typical optoelectronic devices operate at fixed wavelengths defined by the nature of their constituent chemistry, quantum dots can be tuned to absorb or emit light of different wavelengths simply by varying their size.

Quantum dots work this way because the electrons moving within them "feel" the nearby boundaries of the semiconductor. That's because the quantum-mechanical waves associated with these electrons are constrained by the margins of the dots. As is the case with sound vibrations reverberating in a box or microwaves reflecting back and forth in a cavity with conductive walls, the size of the container determines which wavelengths can exist within. For semiconductor quantum dots, increasing the diameter of the particles from, say, 1 to 10 nanometers shifts the action from the visible portion of the spectrum well into the infrared.

Early research in this area mostly involved embedding quantum dots relatively sparsely in a semiconducting polymer. Investigators believed that if they didn't keep the dots spaced well apart this way, they wouldn't remain tuned to the desired wavelength. But in 2007, my colleagues and I omitted the polymer entirely and merely glued the dots

THIN FILM: To create an experimental device, a drop of a quantum dot–rich solution is placed on a 2.5- by 2.5-centimeter glass plate that has already been coated with a transparent electrode [left]. Held to the central shaft by suction, the glass plate is rotated rapidly, forming a thin, even coating of quantum dots [center]. After the solvent evaporates, an array of metal electrodes is deposited on top [right]. PHOTOS: EDWARD H. SARGENT

together using extremely small organic molecules. We laid a quarter-micrometer film of this material on top of a transparent electrode, and although the quantum dots clumped together, they worked just fine—indeed, better than dots dispersed in a polymer did.

Such quantum dots make for good solar cells. Here's why: When a photon hits a dot, it kicks an electron free of the nanoparticle, leaving behind a deficiency of negative electric charge, or a "hole" in the lingo of semiconductor mavens. The hole acts like a positive charge; the electron is, of course, a negative charge. So they are attracted to each other and stay together in the same way that a hydrogen atom's single electron orbits its single-proton nucleus.

To get electrical current out of a quantum dot–based photovoltaic cell—or any solar cell for that matter—such electron-hole pairs must be broken up, with the electrons going in one direction (to the negative electrical contact of the cell) and the holes going in the other (to the positive contact). In conventional organic solar cells, the separation of charges comes about because two types of organics are used—one attracts mobile electrons while the other draws holes into it. When the two types of polymers are joined, electrons and holes created by the absorption of incoming light move in opposite directions, providing an electrical current to drive the load attached to the solar cell.

Whereas organic chemists focus on the materials' different affinities for electrons or holes, electrical engineers view the resultant driving force as arising from an internal electric field. In our cells, we use only one type of photosensitive material, so it's not immediately obvious where this internal electric field comes from. Remember, though, that the quantum dots are sandwiched between two electrodes. One electrode is a piece of glass coated with indium tin oxide, a transparent conductor. The other is just a metal—magnesium or aluminum in our experiments. We found that different metals produce widely different results, which leads us to believe that the internal electric field of our solar cells forms at the boundary between the metal and the quantum dots.

The great thing about these cells is that they are so easy to make. Coating glass with indium tin oxide is routine. (Liquid crystal displays, for example, have such glass electrodes.) And painting this transparent electrode with a film of quantum dots is simple enough. We did that with a technique called spin coating, which spreads a droplet of a quantum dot–rich solution evenly over a rapidly rotating surface. It's a little like the system you sometimes see kids using to drip paint on rapidly spinning cards, which spreads the paint outward into colorful patterns. All we had to do was deposit metal on top of the film to serve as the second electrode.

The solar cells we've built this way have very respectable efficiencies already, and we expect to do even better. But there will be other hurdles to overcome. For one, we have to find chemistries that remain stable over time. Our earliest photovoltaic cells lasted only a few minutes in air. Now we have devices that can operate for days and even weeks while exposed to regular room air. And they'll work much longer when encapsulated in an air-free plastic package. Just as it took engineers many years to figure out how to build organic light-emitting diodes that could shine for decades, developing the chemistries and packaging that will allow these solar cells to function for decades will take a great deal of time and effort. But I see no reason why it won't eventually happen.

Much closer to commercial development are quantum dots that are exquisitely sensitive to faint infrared light. With only a few years of research behind them, these devices now perform as well as the best traditional infrared detectors.

One reason these new quantum-dot sensors work so well is that they provide a built-in gain: Each photon of light produces not just one but many electrons of output current. Since 2004, when Victor I. Klimov of Los Alamos National Laboratory and his team first measured this effect in quantum dots, other scientists questioned the observations, which only indirectly showed multiple-electron generation. But this past summer my research group confirmed this phenomenon by measuring the actual current flowing in real devices. That showed beyond a shadow of a doubt that multiple-electron generation was going on.

In this regard, quantum dot–based sensors are similar to another kind of light detector: the tried-and-true photomultiplier tube. But quantum-dot detectors work very well at infrared wavelengths, while infrared photomultipliers are costly, noisy, and hard to integrate with an imaging chip.

As is the case also for photomultiplier tubes, a small amount of current will flow when a voltage is applied across these quantum-dot devices, even in complete darkness. We figured out how to minimize this background current and its fluctuations by optimizing the chemistry of the starting solution of quantum dots and the films we made from it. In the end, our devices achieved record-breaking, indeed near-ideal performance. They are as sensitive as the indium gallium arsenide photodiodes currently being used for detecting light at infrared wavelengths that are well separated from the visible spectrum.

PEA SOUP: Infrared light is less prone than visible light to scattering. So infrared wavelengths that are well separated from the visible spectrum penetrate well through fog [top two photos] and smoke [bottom two], making scenes clear that would otherwise appear murky. The cameras used to obtain such infrared pictures are, however, expensive. Quantum dot–based sensors promise to make such imagers more affordable.

PHOTOS: SENSORS UNLIMITED, PART OF GOODRICH CORP.

Paint-on technology simplifies the construction of image sensors enormously. No longer do you need to fabricate the matrix of sensor elements from exotic semiconductor materials. Instead, you can use standard silicon fabrication technology to lay down any pattern you want. A quick overcoat of the quantum-dot film then gives you an imaging device that registers infrared light.

What could you do with such infrared cameras? Lots. For example, you could use them to see through what otherwise would be an impenetrable fog—infrared light being less prone to scattering off water droplets. Or you could produce image sensors tuned to a wavelength of 1.7 µm, which matches the peak of what atmospheric physicists call hydroxyl nightglow. This is the faint infrared radiation given off by excited hydroxyl (OH) groups high up in the atmosphere.

We don't normally think about this radiation, because it's at a wavelength that's invisible to our eyes, but if it were shining down on us at visible wavelengths, the night sky would never seem very dark. Deep twilight would be about it, with only the brightest stars ever becoming visible. With an imager sensitive to this infrared wavelength, outdoor scenes at night would be easy to view. It doesn't take much imagination to appreciate the appeal of such sensors for security, police, and military operations. And because of how they will be made, these stunning new imagers needn't be particularly pricey. I can say that with confidence because I am working right now to commercialize quantum-dot image sensors.

Although a little further off, another project my research team has been working on may also prove its value in the marketplace. We've created a device that can modulate the amplitude of the infrared light reflecting off it. Such modulators can be used to add an information-bearing signal to a beam of light, typically one coming from a laser. While other research groups produced quantum-dot infrared modulators before we did, in 2008 ours became the first to break the 1-megahertz barrier. That's key, because modulation speed translates directly to the bandwidth of the communications link. And modulation rates better than 1 MHz mean that truly useful megabits-per-second communication rates are within reach.

What's more, making these modulators out of easily applied quantum dots allows you to create devices big enough to work with low levels of incident light. So it wouldn't be hard, for example, to fashion a helmet or shoulder patch that would let soldiers communicate with an aircraft shining an infrared beam on them. Unlike the case with radio, such a link would be hard to eavesdrop on.

As with any form of cutting-edge research, plenty of challenges remain in the field of quantum dot–based infrared optoelectronics. And the development of practical devices will require a lot more than just the kind of fundamental research that's gone on so far. Someone will also need to tackle the many engineering problems involved—how to apply the dots uniformly over large surfaces, how to stabilize the resulting films, and how to mass-produce the ultimate product. I don't mean to minimize the difficulty of these many nuts-and-bolts engineering issues. But I am optimistic, especially considering the fundamental barriers that researchers have lately overcome.

As this technology matures, the devices built with it will surely turn out to be much less expensive than the semiconductor chips or wafers used to handle these jobs today. Indeed, when the fabrication of optoelectronic devices becomes almost as easy as splashing paint on a canvas, our normal assumptions about the high cost of high-performance optoelectronic devices will be turned on its head.

Wouldn't it be grand if, for example, people no longer had to struggle with the problem of harvesting solar energy economically? If mixtures of quantum dots help to accomplish that goal, future generations will surely appreciate them more than any paints ever before devised, even those Vermeer and Gauguin once concocted. ❑

TO PROBE FURTHER Additional information about the author's research on optoelectronic devices is available at http://www.light.utoronto.ca.

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Forum

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interview with a cognizant official, the ministry would respond only to a series of written questions. I quoted at length from the spokesman's brief written answers, which were received weeks after my initial deadline. The answers, despite my requests, did not elaborate on specific issues. I also contacted Siemens, which designed the plant, hoping to get some technical details directly from the company. Although Siemens was initially responsive, after I mentioned that I wanted to write about the plant in Gaza, the spokesperson did not respond to subsequent e-mails.

We at the Gaza Electricity Distribution Co. are not satisfied with the article. I was in the meeting between the writer and Suheil Skeik, GEDCo's general manager. The writer did not mention that GEDCo tries to do its job as well as it can (distribute electricity, maintain the low- and medium-voltage networks, and collect the electricity bills, our duty by law). We don't disconnect needy people.

Now we are faced with a 25 percent electricity deficit; in the peak of last summer it was 30 percent and may even pass 30 percent this winter. By law, we must collect 100 percent of the bill despite the fact that more than 80 percent of the Palestinian people in the Gaza Strip live under the poverty line. We stretch our salaries and operational expenses and pay the Palestinian Authority for the purchased electricity. We must manage this with only 700 employees. At the GEDCo warehouse, 240 items are currently in short supply, and 73 of them are at zero quantity.

Skeik did not mention radical solutions. He said that the Gaza Strip has been in a state of electricity deficit since the 2006 bombing of the power plant transmission system, that we need a strategic solution, and that it would be nice to have three reliable sources of energy (from Israel, from our own power plant at full 140-megawatt capacity, and from Egypt through 220-kilovolt linking, which would give the Gaza Strip 300 MW and end the deficit). Skeik said that we face some difficulties due to Israel's policy on material needed for maintenance and development projects.

It is very hard to build in this situation, and it is hard to keep rebuilding when what takes years to rebuild is destroyed in a moment. However, we will keep our hopes up, and we will continue building our country and serving the people.

Usama Dabbour
External Unit, GEDCo
Gaza

To understand the impoverished infrastructure described in the article, a summary of events is required. To start, from Israel's withdrawal in 2005, infrastructure was never a priority for the Palestinian Authority, Hamas, nor for the public at large. American Jews

> "While the author sympathetically portrays valiant, resourceful Gazan Palestinians overcoming the hardships of an impoverished infrastructure, keep in mind that they're suffering the misery of their own making" —*Robert M. Braun*

had provided US $14 million worth of new greenhouses to supplement the ones that already supplied 20 percent of Israel's agriculture. After Israel's withdrawal, Gazan Palestinians pillaged and destroyed over 800 of the greenhouses. Then in March 2007 at least five people were killed after a sewage treatment pool collapsed and flooded a village. The Palestinian Water Authority blamed the aid boycott for the failure to upgrade the outdated plant, but Stuart Shepherd, the United Nations' humanitarian aid officer in Gaza, said that the plant had not been affected by the boycott and that there had long been warnings about the plant.

The boycott that is blamed for the misery in Gaza began in 2007 when a majority of Gazan Palestinians voted for Hamas—which campaigned on a pledge to clean up government and to seek Israel's destruction—passing over political parties that also pledged clean government but also peace with Israel. Soon after the election, Hamas violently ejected the Palestinian Authority from Gaza and promptly spent $30 million of its international aid on munitions and increased the level of rocket attacks on Israel. Because this violated pledges to spend aid only for humanitarian purposes, further aid was withheld. Nonetheless, Hamas still enjoys widespread popular support. A 2009 report by the Palestinian Center for Policy and Survey Research noted that 67 percent of all Palestinians support armed attack against Israeli civilians inside Israel.

Until Israel's Operation Cast Lead at the end of 2008, 1750 rockets and 1528 mortar bombs fired from the Gaza Strip struck southern Israel. Most were locally made, diverting electricity and other resources from infrastructure projects. The tactics are called terrorism for a reason. Studies have documented an entire generation of children traumatized by the terror of rocket strikes and the helplessness of adults to ensure their safety.

So while the author sympathetically portrays valiant, resourceful Gazan Palestinians overcoming the hardships of an impoverished infrastructure, keep in mind that they're suffering the misery of their own making. Were they to instead employ the same ingenuity and energy in building a civil society and living in peace with their neighbors, the story would be brighter for everyone.

ROBERT M. BRAUN
Rockaway, N.J.

FOR THE first time in 35 years, I am ashamed to be a member of IEEE. For 125 years, our association has maintained its professionalism and scholarship. It is a travesty that you have published such a transparently biased political piece in *Spectrum* under the guise of a technical article, with no significant technical content. If the full complexity of the suffering in this region were to be explored, an entire issue of *Spectrum* would have to be devoted to a thorough and balanced analysis. This article certainly failed to do that. If you are now going to run opinion pieces, there should be a point-counterpoint article. However, this type of discourse is already excessively served (and abused) in the popular media and does not belong in IEEE publications.

A. ROBERT SPITZER
IEEE Member
Southfield, Mich.

REALLY DISAPPOINTING to see a technology publication such as *Spectrum* hijacked by a political agenda, with a cover story and photograph completely inappropriate for an IEEE magazine. While the article purports to show the humanitarian and logistical aspect of an engineer's work in a conflict zone, it actually devotes more space to the political, military, and historical situation of the conflict itself, with a heavy bias in favour of one of the sides involved. In doing so, it uses unreferenced and unverified figures (for example, the number of Palestinians killed in Operation Cast Lead—and how many of them were combatants—is highly disputed by Palestinian and Israeli sources). If it had been of a technical nature, a manuscript of this standard would not have passed a peer review process.

Dan Yanson
IEEE Member
Haifa, Israel

This article is short on engineering and long on selective history and politics. You have to read between the lines to see the inconsistencies. We read that Siemens won't repair the transformers unless their technicians are protected by private security guards. This is not for fear of the Israelis—guards don't deter fighter jets. Siemens is worried about Gazans kidnapping the technicians, even as they repair a vital utility. Where else in the world would a party that actively fosters an effective state of war demand a steady supply of power, water, food, fuel, and medicine from its declared enemy?

Alan Fisher
via spectrum.ieee.org

> "To fully explore the complexity of the suffering in this region, an entire issue would have to be devoted to it" —*A. Robert Spitzer*

With all due respect, I must mention that damage to civilian infrastructure in Gaza (and the West Bank) isn't always incidental but quite intentional. Investigations by Amnesty International, as well as other independent nongovernmental organizations and agencies, have found that civilian infrastructure—such as for power, water, sewage, government, education, and medical treatment—are at times intentionally targeted. Also, one year after the Gaza action, infrastructure remains in tatters due to the blockade, now over two years old, of the Gaza Strip. Equipment, materials, and supplies required to build or make repairs are prevented from entering the strip in adequate amounts. A report by Oxfam, Save the Children, AI, and about a dozen other humanitarian and human rights organizations was just issued on the current situation in Gaza: See http://amnesty.org.uk/uploads/documents/doc_20012.pdf.

Edith Garwood
Country Specialist
Amnesty International USA
Charlotte, N.C.

IEEE, I will not cancel my membership. So the article is high on biased politics and a bit low on technology. So the caption on the photo is one-sided. What else is new? Engineers are big boys and girls who have to deal with politics in their jobs all the time. Engineering solutions cannot be only technological. Finding power for the Gazan population, even if their elected leaders are causing the problem by attacking Israelis, is still a valid goal on behalf of that population. Gazan engineers are the right

> "Engineering solutions cannot be only technological. Finding power for the Gazan population, even if their elected leaders are causing the problem by attacking Israelis, is still a valid goal on behalf of that population. Gazan engineers are the right ones to take responsibility for that task. Why shouldn't IEEE members get to read about those challenges?" —*Tom Harris*

ones to take responsibility for that task. Why shouldn't IEEE members get to read about those challenges? We are intelligent enough to read between the lines and filter out the bias. If we weren't, the transistor would have never been invented.

Tom Harris
via spectrum.ieee.org

Attempting to deliver power and communications to a community in the face of political and military suppression is hardly an isolated experience. Right here in the United States, most neighborhoods immediately surrounding major university campuses are subjected to media-sanitized versions of the experiences described in this article. I can with some experience say that what the Palestinians need is distributed generation and switching, not the centralized approach that they clearly have.

Ed Patterson
via spectrum.ieee.org

This is an interesting piece about the difficulties of making things run under challenging circumstances, no matter what the cause. Were IEEE to publish an article on the difficulties faced by other groups or states—say, in Nepal, East Timor, Sudan, Afghanistan, or countless others—I doubt the comments would be as heated. I applaud IEEE for publishing this piece and shedding light on the simple difficulties faced by Palestinian engineers and professionals.

"Professor H"
via spectrum.ieee.org

As engineers, we carry a responsibility beyond the technical. Our work may be supported by a constructive environment or hindered by war and political obstacles. It was enlightening to learn of the resource-limited and hostile environment that these innovative, resourceful, and brave engineers must work in on a daily basis, around the clock. I disagree that the article conveyed political bias. The article was about the heavy burdens that we as engineers must often carry under inhospitable conditions, as the Gaza engineers continue to do. If this is political bias, then as professionals we should question our ability to carry out our social responsibilities.

"Expers"
via spectrum.ieee.org

Thank you for "Powerless in Gaza." I confess I am not exactly an avid reader of the magazine. Many times I just put it aside when I get it. But this time the cover photo caught my eye, and I read the article. Many people in Israel (and I assume in the United States as well) prefer to ignore the devastating situation in Gaza (and Israel's large responsibility for it). Your article may remind them of this.

Dana Ron
Engineering faculty, Tel Aviv University

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Dean
of Computer and Communication Sciences
at Ecole polytechnique fédérale de Lausanne (EPFL)

EPFL is conducting an international search for the Dean of the School of Computer and Communication Sciences, to take office by the fall of 2010.

EPFL, located in Lausanne (Switzerland), is a leading European University and a dynamically growing and well-funded institution fostering excellence and diversity. It has a highly international campus at an exceptionally attractive location and a first-class infrastructure. As technical university it covers computer & communication sciences, engineering, environmental, basic and life sciences, management of technology and financial engineering. It offers a fertile environment for research cooperation between different disciplines.

The School of Computer and Communication Sciences, with 42 faculty members, has experienced a strong development over the recent years to one of the top departments in its area in Europe. The School enrolls about 700 students in its bachelor and master programs in computer science and communication systems, has a highly competitive doctoral program with 300 PhD candidates recruited world-wide and hosts important industrial and research centers, such as the Swiss National Center of Excellence in Research in Mobile Information and Communication Systems and industry lablets by Nokia, SwissCom, and Logitech.

The Dean bears the overall responsibility for the school in matters of education, research, finance and organization and reports to the President of EPFL. The position offers competitive compensation and tenure at full professor level. Candidates should have an outstanding academic record, a strong vision for the development of the faculty in research, teaching, and technology transfer, proficiency in recruiting, and exceptional leadership, communication and management skills. EPFL will provide the means to realize a strategic development of the school over the coming years with the objective to establish world-class leadership in education and research.

The School of Computer and Communication Sciences Dean Search Committee invites letters of nomination, applications (vision statement, complete CV, and the name of up to 5 professional references), or expressions of interest. The screening of applications will start on **March 1st, 2010.** Materials and inquiries should be addressed, preferably electronically (PDF format) to:

Prof. Karl Aberer
Chairman of the Search Committee
e-mail: karl.aberer@epfl.ch

More information on EPFL and the School of Computer and Communication Sciences can be found at **http://www.epfl.ch** and **http://ic.epfl.ch** respectively.

EPFL is committed to balance genders within its faculty, and strongly encourages women to apply.

FACULTY POSITIONS IN
College of Photonics
National Chiao Tung University
at Tainan, Taiwan

The College of Photonics invites outstanding researchers for 8 faculty positions for the Assistant / Associate / Full / Chair Professor ranks. The starting date of faculty positions is **Aug. 1st, 2010**. The applicants with demonstrated strength in research and commitment to teaching in graduate level can choose one of the following Institutes of interests:

- **Institute of Photonic System:** nano-photonics, silicon-photonics, optical system design, optical fiber communication systems, photonic sensing systems, MOEM integrated systems, etc.
- **Institute of Lighting and Energy Photonics:** green-photonics, photonic materials, solar cells, solid state lighting material and devices, etc.
- **Institute of Imaging and Biomedical Photonics:** image display, biomedical photonics, biomedical image, bioelectronics, cognitive neural engineering, etc.

National Chiao Tung University at Hsinchu, Taiwan, has long been a leading research university in Taiwan with strong focus on electronic engineering, computer science and photonics. Based on those well-established research power in Hsinchu, at 2009 the College of Photonics and the Interdisciplinary Photonic Research Center at Tainan campus are built up to complimentarily strengthen the basic and applied research in X-Photonics, where X stands for nano, green, bio, information, and everything, and to enhance the cooperation and develop the key technology with the neighboring photonic industries and in the long run to become a cutting-edge photonic research center in the world.

Applicants should have Ph.D. degree and send curriculum vitae, list of publications, current research and research interests, and 3 recommendation letters to College of Photonics, National Chiao Tung University, Tainan Office. The address is No.301, Gaofa 3rd Rd., Guiren Township, Tainan County, 71150, Taiwan (R.O.C.) and E-mail: *cop@cc.nctu.edu.tw*. Tel: 886-6-3032121 Ext.57735, Fax: 886-6-3032535

More information: **http://www.cop.nctu.edu.tw/**

جامعة كارنيجي ميلون في قطر
Carnegie Mellon Qatar
School of Computer Science
Qatar Foundation

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Carnegie Mellon University in Qatar invites applications for teaching-track positions at all levels in the field of Computer Science. These career-oriented renewable appointments involve teaching international undergraduate students, and maintaining a significant research program. Candidates must have a Ph.D. in Computer Science or related field, substantial exposure to Western-style education, outstanding teaching record and excellent research accomplishments or potential.

Specifically, we are seeking candidates with expertise in databases, data mining, web technology and human-computer interaction, or with substantial experience teaching introductory progamming courses. Truly exceptional candidates in other areas also will be considered.

The position offers a competitive salary, foreign service premium, research seed grant, excellent international health coverage and allowances for housing, transportation, dependent schooling and travel.

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For further information or to apply, visit
http://www.qatar.cmu.edu/cs/positions/

جامعة تبوك
University of Tabuk

University of Tabuk, Kingdom of Saudi Arabia

Department of Electrical Engineering

Faculty Positions

The Department of Electrical Engineering at the University of Tabuk in Saudi Arabia is seeking applicants for faculty positions in all fields of Electrical Engineering. University of Tabuk is a brand new state university whose ground breaking was in 2006. It aspires to be a premier research institution in the Middle-East. Faculty positions are open at the Assistant, Associate and Full Professor levels and will commence in September of 2010. At the time of appointment, candidates must have earned a doctorate in Electrical Engineering or a related field. Specific duties include the development of internationally recognized research programs, undergraduate/graduate teaching and advisement, as well as service activities. Candidates will have the opportunity and be encouraged to develop research partnerships with internationally recognized centers on campus and in the United States of America. University of Tabuk already has in place research agreements with premier research universities in the USA, China and Europe. Nanotechnology applications in all fields are of special interest to the University and the Kingdom. The University is in the process of establishing a major research center for nanoelectronics. Interested candidates are invited to submit a letter of application, a comprehensive curriculum vitae, a summary of teaching and research interests and the names and contact information of three references. All materials should be sent electronically as a .pdf file to

UofTabuk@yahoo.com

The review of applications will begin immediately and the selected candidates will be interviewed in New York City in March 2010. The salary scale for Assistant Professors is 12,540-14,500 Saudi Riyals (SR), for Associate Professors 16,000-18,000 SR and for Full Professors 20,000-22,000 SR per month for a 12 month period. Faculty members can earn an additional two summer months of pay from their research grants. Faculty members also receive two months of paid summer vacation. There is also an additional 25,000 SR annual housing allowance and a onetime 18,000 SR furniture allowance. Saudi Arabia is a tax free country and the preceding salary amounts are take-home net pay. The currency exchange rate is 3.75 Saudi Riyals to 1 USD. The language of instruction at University of Tabuk is English, and due to the presence of a very large international expatriate community, applicants for these positions do not have to be Arabic speakers. Self motivated candidates who would enjoy the challenges of starting a new well-funded program are especially invited to apply.

Tabuk is in the northwest corner of Saudi Arabia, near the Jordanian Border, and close to the Red Sea with some of the most pristine beaches in the world. Further information about these positions can be obtained by calling

1-585-765-5134

Full Professorships at the Faculties of Engineering, Science and Medicine, Aalborg University, Denmark.

The Faculties of Engineering, Science and Medicine have decided to invest in strengthening their research programs in basic research within selected disciplines, where new ground breaking results could have potentials for being of vital importance for new, smarter and sustainable solutions to globally important problems.

The purpose of the new professorships is to strengthen the "new type" of university research environment, where basic research interacts closely with solution focused research. The aim is to create breeding ground for shorter time from conceptual breakthroughs to societal and business impact; and at the same time to grow the faculty with even more international level role models for the young researchers. Mutual inspiration comes as an added benefit for the scientists involved as well as the students and the partners.

The positions (position no. 60030) are a part of the Danish Globalisation Programme and are open for appointment beginning June 1st 2010 or soon thereafter for a period of 3-5 years and will be filled in one or more of the following research areas:

ICT Energy Solutions • Physics of Nanomaterials • Energy Storage Technologies Translational Pain Research • Neurobiology and Motor Learning

In order to apply for this position, all applicants must read the complete job notice at: ***http://stillinger.aau.dk/***.

Enquiries may be addressed to:
Dean, Professor Frede Blaabjerg, by e-mail: ***fbl@adm.aau.dk*** or mobile: +45 2129 2454.

Deadline for applications is: April 1st 2010.

The mission of Aalborg University (AAU) is to ensure high quality in higher research and education within the fields of Engineering, Natural Sciences, Medicine and Social and Human Sciences. Leading the way in pedagogical teaching, Aalborg University uses Problem Based Learning (PBL): a unique teaching model close to optimal for the learning process. With an annual budget around DKK 2 billion, more than 15,000 students, 600 Ph.D. students, more than 2,000 employees and strong ties to industry and business life, Aalborg University has established its position as a considerable force within higher research and education both nationally and internationally.

AALBORG UNIVERSITY

International Adjunct Teaching Positions

Electronics: Vaughn College of Aeronautics and Technology invites applications for adjunct faculty positions to teach undergraduate avionics in three-week sessions at Vaughn's additional location in Hyderabad, India. The faculty will be responsible to teach 20 hours of lecture and 45 lab hours on-site during the three weeks, which will be followed by 10 hours of instruction online.

Applicant must be a US citizen and possess a master's degree in electronics, doctoral degree preferred. Those with only an undergraduate degree will not be considered. Related avionics industrial experience is required. Prior teaching experience including online courses is a plus. Teaching responsibilities include such courses as aircraft communications, navigation systems and radar systems. Attractive compensation along with travel and boarding expenses provided. For more information about Vaughn, visit ***www.vaughn.edu***.

To apply: Send curriculum vita, and cover letter to the Assistant Vice President of Human Resources and College Services, Vaughn College, 86-01 23 Avenue, Flushing, NY, 11369, fax to 718.651.2553, or e-mail at ***paul.miranda@vaughn.edu***. Vaughn is an EEO/AA employer.

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Professorship in Electromagnetic Fields and Waves

The Department of Information Technology and Electrical Engineering at ETH Zurich (www.ee.ethz.ch) invites applications for a professorship in Electromagnetic Fields and Waves. The successful candidate should have a strong record of accomplishment related to theoretical and computational aspects of electromagnetic fields and waves. His or her particular research area may come from a broad range of subjects such as computational electromagnetics or optics, antenna design, electromagnetics of biological tissues, applications of electromagnetics and optics in biology and medicine, microwave techniques, millimeter-wave communications, radar and RF sensing, optical interconnects, photonics, plasmonics, and functional metamaterials.

Applicants should have a Ph.D. degree and an excellent track record in one or more of the above mentioned areas and should be able to teach at all university levels. The new professor will be expected to teach undergraduate level courses (German or English) and graduate level courses (English). The position can be filled at either assistant professor (tenure track) or full professor level, depending on the age, scientific experience, and record of the applicant. Assistant professorships have been established to promote the careers of younger scientists. The initial appointment is for four years with the possibility of renewal for an additional two-year period and promotion to a permanent position.

Please submit your application together with a curriculum vitae, a list of publications and a list of research activities and projects **to the President of ETH Zurich, Prof. Dr. Ralph Eichler, ETH Zurich, Raemistrasse 101, 8092 Zurich, Switzerland (or via e-mail to faculty-recruiting@sl.ethz.ch), no later than April 30, 2010.** With a view toward increasing the number of female professors, ETH Zurich specifically encourages qualified female candidates to apply.

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the data

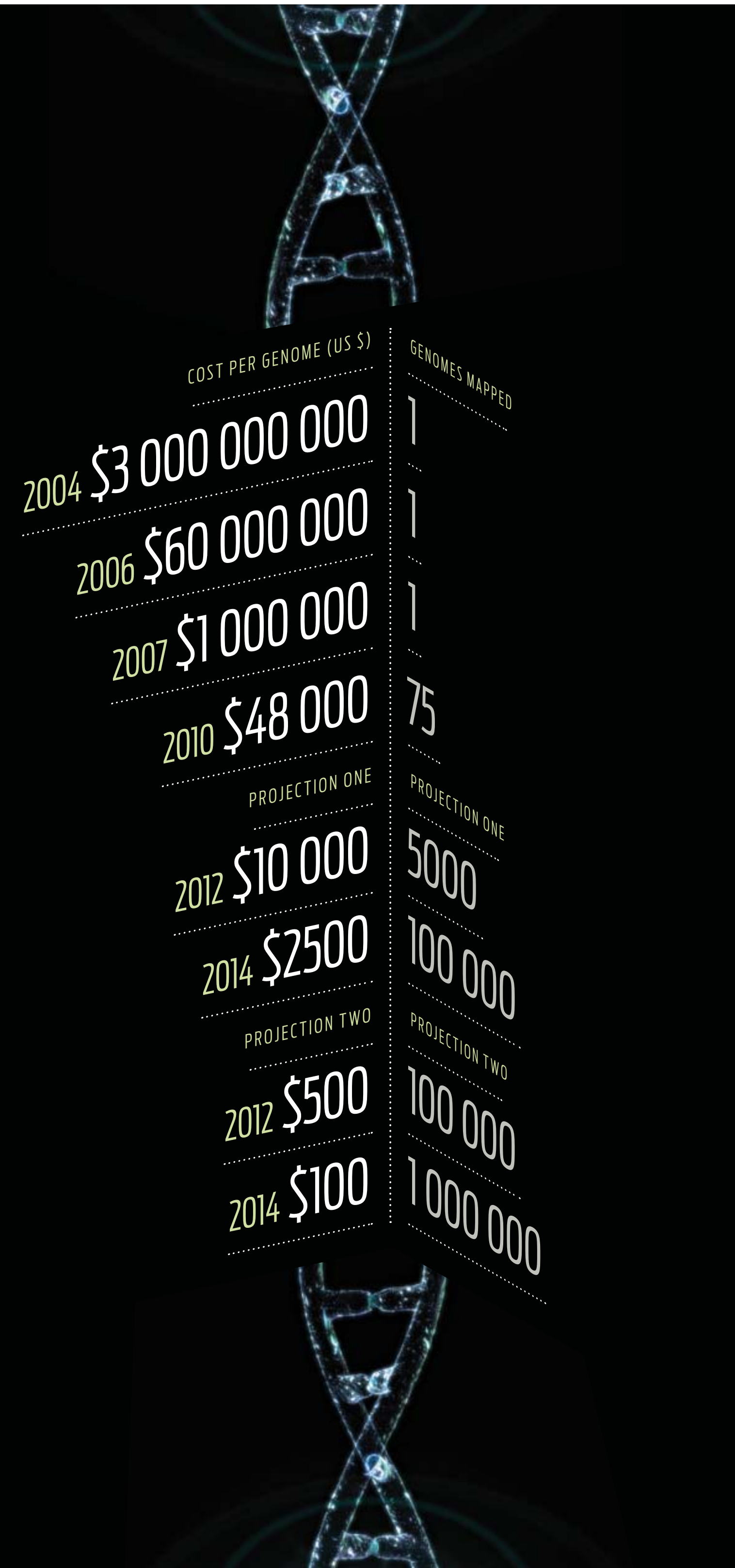
The Road to the Personal Genome

IN THE space of a single decade, the cost of mapping all your DNA will fall from the billions of dollars to the thousands. The human genome is becoming a commodity virtually overnight. It's as if millions of households could have had dishwashers and vacuum cleaners 10 years after James Watt built his steam engine.

DNA, the "code of life," is the ultimate binary file, a database of 12 billion bits. The data—6 billion matching sets of either the molecules adenine (A) and thymine (T) or guanine (G) and cytosine (C)—affect everything that makes you *you*: the color of your eyes, whether you're moody or cheerful, and which diseases you're most susceptible to.

Today you can purchase your very own personal genome for US $48 000 from Illumina, a San Diego biotech firm (and they'll throw in an Apple iMac). [See "The $100 Genome," elsewhere in this issue.] That's a bit pricey if all you want to do is check out the genetic inheritance of Saturday's dinner date. But by 2014, your genome will cost a mere $2500, according to TSG Partners, an Atlanta-based life sciences advisory firm, so low that health insurance companies might pick up the tab just to get their hands on the data. The current head of the Personal Genome Project, George Church, thinks it will soon be far cheaper than that—perhaps even less than the dinner itself. *—Mark Anderson*

Sources: TSG Partners, Atlanta (projection one) George Church, Harvard Medical School (projection two).



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