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FOR THE TECHNOLOGY INSIDER | 02.14

Rocket Man

BRANDON PEARCE IS HELPING TO LAUNCH A NEW ERA IN SPACEFLIGHT

DREAM JOBS SPECIAL REPORT P. 35

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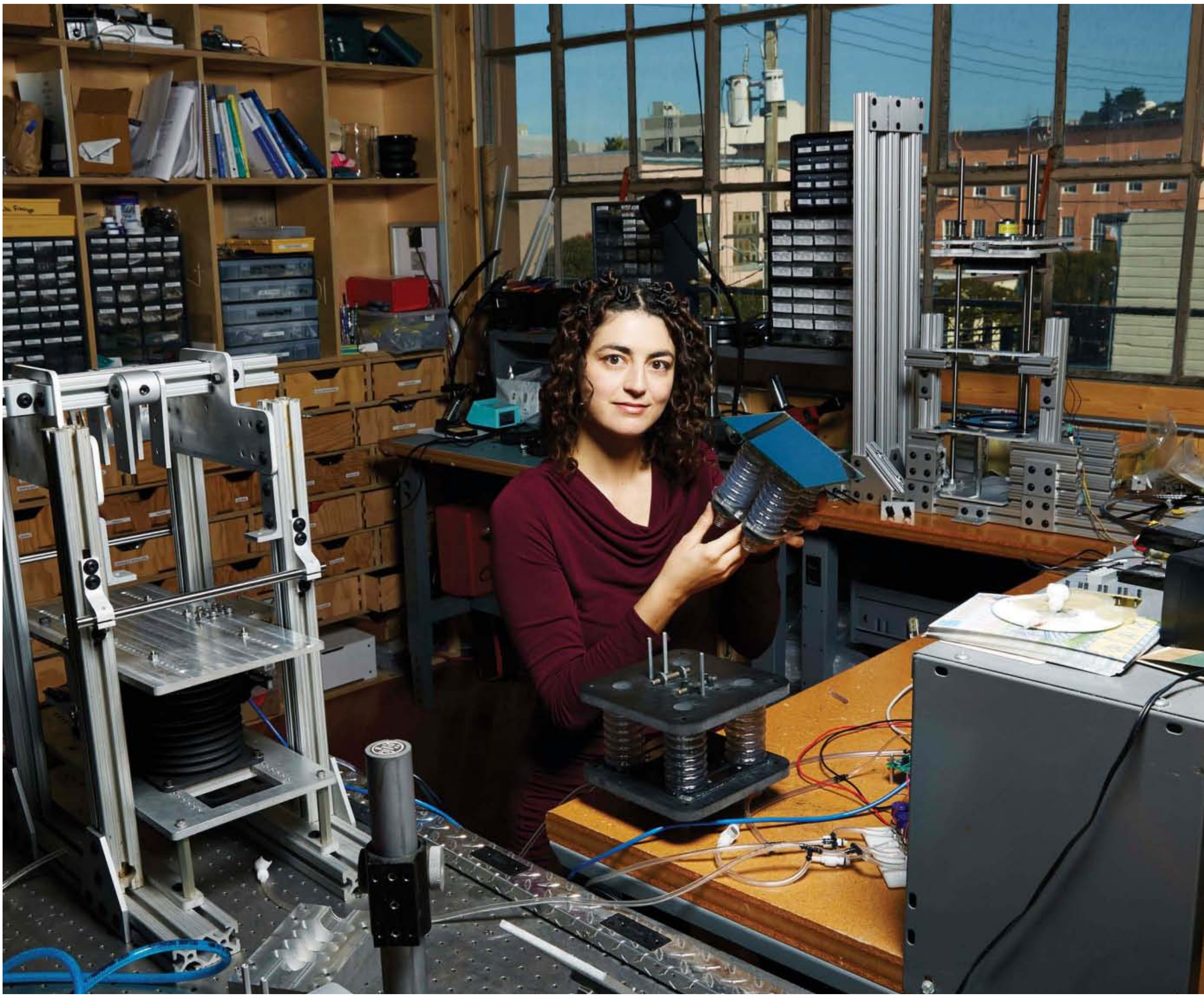

On the Cover **Photograph for *IEEE Spectrum* by Gregg Segal**

COVER RETOUCHING: G-TOU

PHOTOGRAPH BY **Gabriela Hasbun**

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FROM LEFT: CSCS; AEREO; IEEE SPECTRUM

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MARINE ENERGY Many companies that develop technologies to harness energy from tides and waves must test their systems at sea, because few laboratories can duplicate the conditions of the ocean. But two test centers in the United Kingdom will provide a safe and controlled environment.

IEEE'S WIE CELEBRATES 20 YEARS A number of events will celebrate the 20th anniversary of the IEEE Women in Engineering group, including an international leadership conference and live online chats.

BLACK BOX CONCERNS This year, carmakers may be required to equip all new vehicles sold in the United States with an event data recorder to collect diagnostic and performance information. Many people are concerned about the security and privacy of this data, including members of the IEEE Standards Association, which has developed standards addressing these issues.

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BACK STORY_

Special Delivery

PHOTOGRAPHER GREGG SEGAL is used to odd assignments. Three years ago, for instance, *IEEE Spectrum* sent him to Des Moines to document a group of linguistically adept bonobo apes.

For the photo-essay in this issue, Segal and his assistant Tom Mishima went to the far northwest corner of Minnesota, to Thief River Falls (population 8661). The assignment was to bring to life the vast warehouse and corporate nerve center of the global electronic components distributor Digi-Key Corp.

Segal found no shortage of material. He specializes in what he calls the environmental portrait. "It's more than just a picture of a person," he says. "It's in a place that says something about the person."

For this shoot, he says, "finding people who are idiosyncratic and interesting is part of what makes the assignment fulfilling." Like the engineer whose desk is littered with obscure instruments, spare parts, and personal projects, or the warehouse worker captured in a rare moment of repose, an aura of beatitude illuminating her face. "The pictures are about the personality and character of Digi-Key's employees, who seem to represent small-town America," Segal says.

One woman's shrine to Barry Manilow caught his eye. "In her cubicle, she had a disco ball, ticket stubs from shows, a concert poster from decades ago," he recalls. "I complimented her on the display and mentioned that I'd taken the photos for Manilow's last album. She was speechless."

As for the scooter delivery cart in the photo above, Segal says, "As soon as I saw somebody riding one of those, picking up some part from some shelf somewhere, I wanted to hop on." His chance finally came at the tail end of the two-day shoot. "It's an excuse to act like a kid at work." ■

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PHOTOGRAPH BY **Tom Mishima**

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Joachim Fischer, Michael Thiel & Martin Wegener

Metamaterials small enough to work at optical wavelengths were largely theoretical in 2001, when Wegener [right], a professor at the Karlsruhe Institute of Technology (KIT), in Germany, began working on a way to fabricate them using direct laser writing [see "Matter Made to Order," p. 30]. Now, he says, "we can fabricate nearly any three-dimensional architecture from scratch." Coauthor Fischer [left] is a postdoc in Wegener's group. Thiel left the lab in 2010 after completing his Ph.D. to join KIT spin-off Nanoscribe, where he currently heads technical development.

Mark Harris

Contributing editor Harris has previously written for *IEEE Spectrum* about failing defibrillators and firefighter-tracking technology. In this issue, he investigates the sale of thousands of Kodak's patents to a consortium of the world's biggest technology companies [p. 24]. It's a homecoming of sorts for Harris, who over a decade ago wrote his first feature for a national newspaper (*The Independent* in the United Kingdom) on Kodak's revolutionary use of OLED displays.

Gabriela Hasbun

For our Dream Jobs report, Hasbun, a San Francisco–based photographer, did two shoots with opposite technical challenges. For the first, about solar-energy innovator Leila Madrone [p. 40], Hasbun shot indoors, using artificial lights to mimic a lens flare from the sun. The second shoot, of sports-software coder Mark Perry [p. 44], was outdoors, where Hasbun had to carefully avoid getting a natural lens flare in the photos. "I was fighting the light for both," she says.

Paul McFedries

McFedries has written *IEEE Spectrum*'s Technically Speaking column since 2002. In this issue he writes about "urban computing," in which the city itself becomes a kind of distributed computer [p. 22]. McFedries is the author of more than 70 books on software and technology. His website, Word Spy, tracks emerging words and phrases. His "lexpionage," as he calls it, extends beyond technology: He recently wrote a post about "fauxductivity"—busyness that consists of trivial activities.

Lily Hay Newman

Always looking to learn about something new, Newman says that she sees complicated topics not as overwhelming but "vast." In writing about a Swiss supercomputer that's one of the fastest and most energy efficient in the world [p. 11], she was impressed by how tiny processor changes could significantly improve performance. A freelancer based in New York City, Newman cooks or listens to jazz when she wants to contemplate the vastness of the universe.

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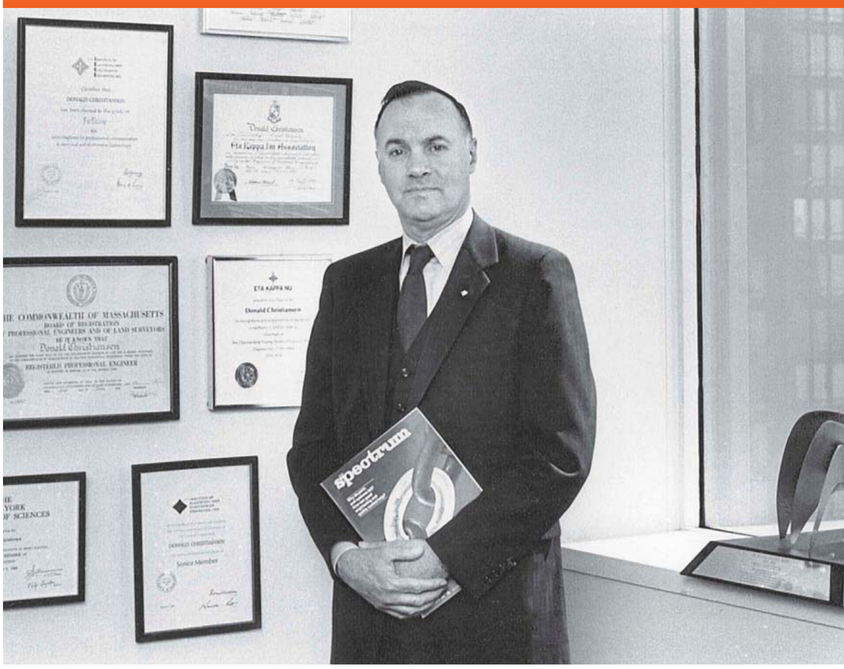

DONALD CHRISTIANSEN

Remember the Reader

Donald Christiansen and the making of *IEEE Spectrum*

Editor's note: In this 50th anniversary year of IEEE Spectrum*, we are using each month's Spectral Lines column to describe some pivotal moments of the magazine's history. Here we celebrate the tenure of* Spectrum*'s first full-time editor, Donald Christiansen.*

IT WAS THE SUMMER OF 1963, and at a staff meeting at *Electronic Design* magazine, the topic of the day was a potentially fearsome new competitor. The IEEE, only a few months old, was about to introduce a magazine. Around the table at *Electronic Design*, there was a palpable sense of concern that the upstart publication, which would be called *IEEE Spectrum,* would draw away readers and advertisers.

But the worry soon passed, says an editor who was at the meeting, when the IEEE revealed that the new magazine wouldn't be led by an experienced publishing hand. In keeping with the usual practice of association publications, the name at the top of the masthead would be that of a part-time volunteer. And his responsibilities would include not only *Spectrum* but all the publications of the individual IEEE societies.

The story doesn't end there. That *Electronic Design* staff editor was Donald Christiansen, and eight years after *Spectrum*'s launch, he took charge of the magazine, to the great benefit of both. During a 21-year run as *Spectrum*'s editor, Christiansen would mold the magazine into the basic form it still occupies today. Under his direction, the magazine would do pathbreaking coverage and analyses of the Bay Area Rapid Transit engineering whistle-blower case, the Three Mile Island nuclear accident, the AT&T divestiture, the space shuttle *Challenger* explosion, the performance of the weaponry in the first Persian Gulf War, the Iraqi nuclear weapons project, and the Shoreham nuclear power plant in New York state. Under Christiansen, *Spectrum* would win four National Magazine Awards, the highest honor in U.S. magazine publishing, along with scores of other honors.

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To appreciate Christiansen's transformation of *Spectrum*, you have to begin with what it was prior to his arrival in late 1971. For its first eight years, the day-to-day running of the magazine was left to a managing editor. That editor—Elwood K. Gannett at first, and Ronald K. Jurgen later—pursued sound journalism. But the lack of publishing expertise and vision at the top of the masthead put the magazine at a disadvantage.

In those days, *Spectrum* competed with formidable and well-run magazines for advertising and readers. They included not only Hayden Publishing's *Electronic Design* but also McGraw-Hill's biweekly *Electronics*—which Christiansen had joined in 1966 and ultimately led as the editor. In the 1960s, it wasn't uncommon for an issue of *Electronics* to have 250 pages. The magazine had an editorial staff of about 50 people, with bureaus in Bonn, London, and Tokyo. *Spectrum* had half a dozen staff editors in New York and no bureaus at all.

By the early 1970s, Donald G. Fink, the IEEE's first general manager, decided that *Spectrum* needed a professional editor. Fink, who had himself been the editor of *Electronics* before Christiansen, wasn't driven just by the need to compete with professionally run magazines. He also sought to defuse an impassioned debate within the IEEE about what kind of magazine *Spectrum* should be.

Spectrum's last two volunteer editors, J.J.G. McCue of MIT's Lincoln Laboratories and David DeWitt of IBM, had both unflinchingly steered *Spectrum* into some of the biggest technology-related controversies of the late 1960s and early 1970s. One involved a huge U.S. antiballistic missile (ABM) project. *Spectrum*'s coverage included not just technical aspects but also letters and other material that criticized the ABM work on ethical and social grounds. The criticisms in turn provoked a deluge of letters, many of them quite irate.

With input from members, IEEE president F. Karl Willenbrock responded by formulating a policy statement that affirmed *Spectrum*'s mandate to cover controversial topics, so long as "reasonable efforts" were made to include different points of view. The statement also declared that articles in *Spectrum* reflected the author's point of view, not some sort of consensus of the IEEE's officers or, even more improbably, of its many members. (Such a declaration is published to this day on one of the contents pages and below the masthead of every issue of *Spectrum*.)

The controversies repeatedly raised a question about *Spectrum*, Christiansen says: "Who's really running this magazine? It's why Fink finally concluded, 'Look, you've got to have a professional running this magazine,' and he convinced the IEEE board to do it."

Fink, meanwhile, had no doubt about whom he wanted for the job: Christiansen. An IEEE senior member (later a Life Fellow), Christiansen was a Cornell EE grad and had held positions in vacuum-tube and semiconductor-device engineering and management at CBS's electronics division. In his spare time, he wrote for a magazine called *Electronics World*, before becoming a full-time editor in 1962.

Fink asked Christiansen to write a proposal describing what he would do with *Spectrum* if he were the editor. Christiansen's plan was straightforward: Ban mathematical equations (*Spectrum* at the time was full of them); publish shorter, tightly edited feature articles; and include more staff-written features. And he insisted on being not just the editor but also the publisher of *Spectrum*. Fink submitted Christiansen's proposal to the IEEE board of directors, which agreed to all the conditions.

Christiansen's first issue was January 1972. As the staff was finalizing the issue, on 12 December 1971, David Sarnoff died in New York City. So the new editor's first big decision was to order up a new cover story on Sarnoff, to be written in three days. It raised a few eyebrows at IEEE HQ: Technical-business genius though he was, Sarnoff was reviled in some engineering circles, partly because of his vicious patent feud over FM radio with engineering hero Edwin H. Armstrong. Fink, himself dismayed, left the decision to Christiansen. After expressing his reservations, Fink ended with, "But *you're* the editor." Sarnoff stayed on the cover.

And so it began. Christiansen's tenure at *Spectrum*, from 1972 to 1993, was characterized by journalistic vigor and an unwavering focus on the member-reader. In his Spectral Lines columns, he prodded engineers to become more active in their companies as managers and to volunteer their expertise as citizens; he commented on the burning tech-related topics of the day; and he celebrated the simple pleasures of designing something elegant. Whistle-blowing, occupational dilemmas, and the sometimes

SPECTRAL LINES_

conflicting demands of morality and loyalty were frequent subjects. "An employed engineer is sometimes drawn between the purely moral thing to do, and what management would have him do," he says. Under Christiansen, staff editors (full disclosure: For nine happy years, I was one of them) were encouraged to pursue newsy and controversial topics, to follow them wherever they led, and to dig deeper than the mainstream press into the technical details. We were pushed to investigate failures–the bigger the better–and to point fingers and assign blame. And we had to do our homework: Don brought in a copy consultant, a crotchety, old-time newsman named Richard Haitch, who pounded us if we hadn't.

Under that formula, great stories–and journalism awards–soon started piling up. In 1979, *Spectrum* explained to the world exactly what caused the partial meltdown in a reactor core at the Three Mile Island nuclear reactor in Pennsylvania. In 1982, just after the war in the Falklands, we made a wide-ranging assessment of rapidly advancing military technologies. In 1985, the magazine unraveled the chain of events that led inexorably to the breakup of AT&T and correctly predicted what it would mean for the future of communications. And in 1992, we revealed how Iraq tried to build an atomic bomb, and how the discovery of that clandestine effort led to new ideas about safeguarding nuclear weaponry. All four of those investigations won National Magazine Awards, putting *Spectrum* among the very few–count 'em on one hand–association magazines ever to win the awards repeatedly.

In a world growing more turbulent, complex, and hostile, he relied on ethics, professionalism, and his readers' interests

Today, Christiansen writes the popular Backscatter column for *Today's Engineer*, the publication of the IEEE-USA, the IEEE's advocacy group for U.S. engineers. He writes about pretty much whatever he wants, but many columns draw on his first-hand exposure to some of the great events and people during an amazing time in technology. He hasn't lost his passion for professional concerns: For several years he has organized a seminar on engineering ethics for the Long Island, N.Y., IEEE section, of which he is an active member.

In his final column as *Spectrum*'s editor, Don wrote: "*Spectrum* has been criticized for publishing case histories or company profiles complete with the warts that prove engineering designs or management decisions are not always perfect and on occasion are outright disasters. No surprise, the critics were usually those whose oxen were being gored, and occasionally IEEE leaders who feared withdrawal of support for IEEE activities by the corporations under scrutiny. But our readers always responded enthusiastically to articles probing 'what went wrong,' and these continue as staples."

It was classic Don. In a world growing more turbulent, complex, and even hostile, he navigated by relying on ethics, professionalism, and, most of all, his readers' interests. And in so doing, he showed many of us the way, too. –GLENN ZORPETTE

NEWS

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SMALL SWISS SUPERCOMPUTER SHOWS THE WAY AHEAD ON EFFICIENCY

Piz Daint masters both speed and efficiency by keeping data close to its processors

MORE FLOPS, LESS WATTS: The Piz Daint supercomputer gets high marks for both speed and efficiency.

Scan the latest list of the 10 most powerful supercomputers and the list of the top 10 most energy efficient and you'll see that only one name appears on both. The Piz Daint supercomputer is both the sixth most powerful machine in the world and the fourth most energy efficient. It's also one of only two supercomputers in the top 10 of the efficiency ranking (the Green500) that's capable of maintaining petaflops performance—a million billion floating-point operations per second. How it managed to make its mark in both categories could point the way to both more powerful and more efficient future machines.

"What I'm seeing is that energy efficiency is increasingly becoming a first-order design constraint that is on par with performance," says Wu Feng, one of the Green500's leaders and a professor of computer engineering at Virginia Tech. "It's not going to be any good to be high performance but so power hungry that you don't even have the budget to power or cool the system." »

Located at the Swiss National Supercomputing Centre (CSCS), in Lugano, Piz Daint is being used to parse huge data sets and simulate processes for projects in geophysics, materials science, chemistry, and other areas, but especially in climate modeling. To power that research, the computer uses a hybrid system that combines the advanced network architecture of the Cray XC30 with two cutting-edge processors, the Intel Xeon E5 CPU and the Nvidia Tesla K20X GPU. The computer's 5272 compute nodes are bound together in a special low-latency network to form an unusually compact machine. Thomas Schulthess, the director of CSCS, says that Piz Daint uses 28 cabinets to achieve what would take 50 cabinets of the second most powerful computer in the world, Titan, which Schulthess worked on at Oak Ridge National Laboratory, in Tennessee.

But the supercomputer's real secret is that whenever possible its software keeps data from having to travel between processors. "What we really wanted on Piz Daint was to motivate users to consider how they organize their data in applications," says Schulthess. He thinks that optimizing where data resides relative to where it's computed and improving how multiple simultaneous computations can be performed on the same set of data "are the two ingredients to our future algorithms and application design."

Applications that run on Piz Daint, which is named for a mountain in the Swiss Alps, use custom algorithms that intentionally position large data sets for processing on either the GPU or the CPU so the data won't have to be moved much or reconfigured later on. These efficiencies speed computing, because Piz Daint isn't taking time to locate and cull data. They also decrease energy consumption, by reducing data movement between processors and even within one processor in the case of the GPUs.

The machine needed to be built in two steps because the team had to wait for supercomputer manufacturer Cray to release the hybrid version of the XC30 architecture. But Schulthess says this was almost preferable because it gave the CSCS group time to do extensive testing on the smaller network and iron out any kinks before adding the XC30 to create the hybrid system in October.

It was worth the effort. "It's bad to say as an engineer when you're surprised, but Piz Daint in the end was so energy efficient, it was actually better than we expected," Schulthess says.

Feng hopes that Piz Daint's success will encourage other research groups to be more aware of their supercomputers' carbon footprints. This would be a step toward "simulating the climate, not generating it," he says.
—LILY HAY NEWMAN

WATER VERSUS WATTS: The Swiss supercomputer is cooled by water from nearby Lake Lugano.

NSA SURVEILLANCE SPARKS TALK OF NATIONAL INTERNETS

Germany takes the lead in making the Internet local

Just imagine the "network of all networks," the globe-spanning Internet, becoming a loose web of tightly guarded, nearly impermeable regional or even national networks. It seems antithetical to the mythology surrounding the Internet's power and purpose. But ongoing revelations about the extensive surveillance activities of the U.S. National Security Agency (NSA) are pushing countries like Germany and Brazil to take concrete steps in that direction.

Within the 28-member European Union, Germany is taking the lead in pushing for measures to shield local Internet communications from foreign intelligence services. That should come as no surprise. For Germans from the formerly Communist-ruled part of the country, NSA spying sparks bitter memories of eavesdropping by the Stasi, the secret police agency of the former East Germany. Because of that history, Germany has one of the strictest data privacy regimes in the world. On more than one occasion, the country has forced Google and other Internet companies to amend their data collection and usage practices.

For German chancellor Angela Merkel, the revelations are particularly disturbing: The political leader, who grew up under Stasi scrutiny, has had to deal with allegations that her own mobile phone was tapped by the NSA. She's not amused.

"Cybersecurity is no longer a niche topic but a top priority," Deutsche Telekom CEO René Obermann told attendees of the Cyber Security Summit late last year, in Bonn. He noted that his company battles more than 800 000 attacks a day on its networks.

MARCO CAROCARI

JOCK FISTICK/BLOOMBERG/GETTY IMAGES

WHO IS LISTENING? German chancellor Angela Merkel was shocked to learn that the U.S. National Security Agency had been tapping her phone. Germany is considering steps to guard its network.

A number of policymakers in Berlin and the country's network regulator back Deutsche Telekom's efforts to tighten security through "national routing," says Obermann. Essentially, the concept aims to handle data generated in Germany and destined for or used by local end users by means of fiber-optic cables, routing gear, and computers within the country. The aim is to avoid sending data packets through nodes in the United States and the United Kingdom. The operator, which already offers an encrypted "Made in Germany" e-mail service and cloud service, has also suggested expanding the idea to include all 26 countries participating in the borderless Schengen Area in Europe. Deutsche Telekom already carries much of the Internet traffic in Germany via reciprocal, or peering, agreements with ISPs, with the remainder handled by an array of operators, many of them foreign-owned.

The kind of segmenting of Internet communications Obermann is talking about would require operators to have two essential components: a national peering agreement that links the Internet networks of all the service providers; and a routing table, also known as a routing information base (RIB), that describes the topology of the networks. Routing tables maintained by the operators currently contain no instructions to keep in-country packets inside the country. The operators would also need their own German-specific routing protocols, which set down how the routers communicate with each other.

Deutsche Telekom claims it has the technology and know-how and needs just three more peering agreements to be able to provide such national routing. The operator, which is also open to the idea of forming a national routing entity, says more than two-thirds of its e-mail traffic is generated and terminated in Germany, and it is pushing parliamentarians to make the needed agreements mandatory.

European governments aren't the only ones looking to break off from what they see as American control of the Internet. The Open Root Server Network (ORSN) is an alternative network of domain name servers—machines that translate the names of Web addresses into the numbers of Internet addresses. Originally established to counter the fact that most of the domain name servers were in the United States at the turn of the 21st century, it operated from 2002 to 2008, when an expansion of the domain name server system made it defunct. But following ex-NSA contractor Edward Snowden's revelations about the agency's spying, the ORSN has been revived. "We're detached from a single country, like the U.S., which still controls" the Internet Corporation for Assigned Names and Numbers, says Markus Grundmann, one of the network's founders and coordinators.

Beyond Europe, Brazil's president, Dilma Rousseff, is one of the most outspoken heads of state to criticize NSA practices and take action. She is pushing legislation to force Internet companies such as Google and Facebook to store local data within the country's borders. She also wants to build submarine cables that don't route through the United States, set up domestic Internet exchange points, and create an encrypted national e-mail service.

International operators keen to implement some sort of national or regional routing are quick to point out that the practice already exists in the United States. Nationally generated and terminated traffic is prohibited from being routed over nodes outside the country. Foreign carriers with operations in the country must sign a compliance agreement.

But is a Brazilian lockdown or a German "Internetz," as the local media are calling it, the answer to preventing state-sponsored spying and hacking? Many industry experts have their doubts.

"A balkanization of the Internet is not the solution and runs totally contrary to the basic principles of the Internet," says Norbert Pohlmann, president of the German IT security association TeleTrust. He points to the Internet's ability to take advantage of global cost and capacity opportunities to route traffic.

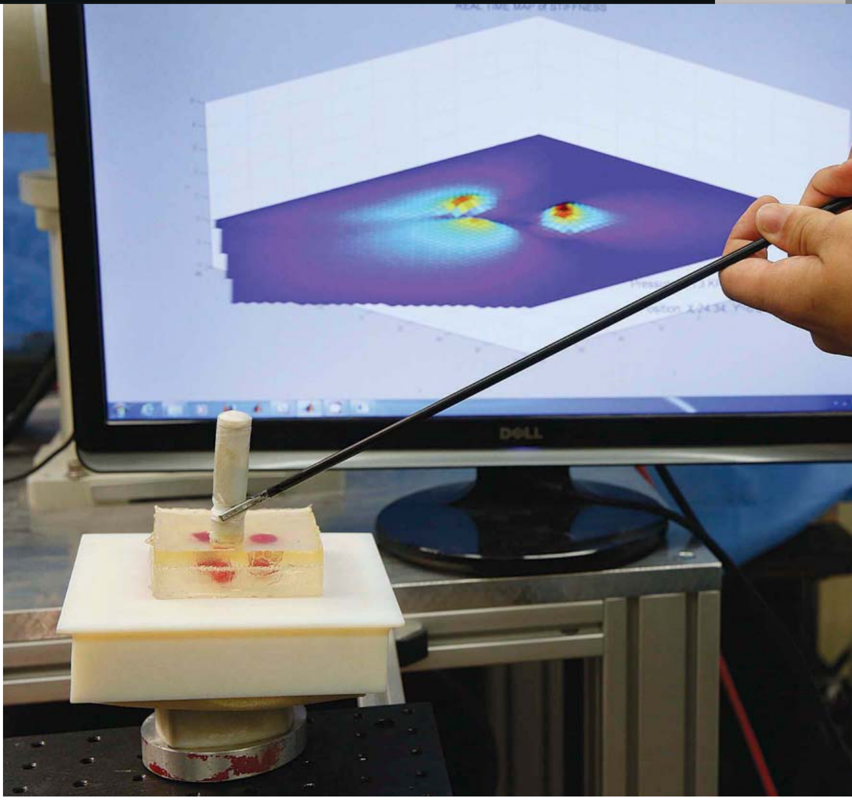
Leslie Daigle of the Internet Society writes that the Internet "was not designed to recognize national boundaries" but rather for resiliency, which is "achieved through diversity of infrastructure: Having multiple connections and different routes between key points ensures that traffic can route around network problems and nodes that are off the air because of technical, physical, or political interference, for example."

That said, Pohlmann argues that the Internet community still needs "a common global infrastructure that ensures a high level of IT security, even if no one can guarantee 100 percent security." He calls on users to rely on end-to-end encryption and virtual private networks, which would make spy-agency snooping difficult.

But Jacob Appelbaum, a developer of the Tor Project, warns that even secure systems like virtual private networks can be rendered useless through misuse of so-called backdoors. Backdoors are essentially software designs in networks that allow authorities to conduct "deep packet" inspection to monitor and intercept data. The European Telecommunications Standards Institute, for instance, works closely with operators, government, and law enforcement agencies to integrate surveillance capabilities into communications networks. But many operators are concerned about how access to the backdoor "keys" is regulated, and, in the case of some equipment vendors–notably China's Huawei Technologies Co.–about whether secret backdoors are built into network systems without operators' knowledge.

Deutsche Telekom's Obermann acknowledges the problem. "We need strong and secure networks in Europe," he says. "Maybe that means we need to make the technology ourselves, or that the technology we buy doesn't provide backdoors."

But don't expect intelligence forces to ever give up trying to penetrate security systems, no matter how advanced they may be, cautions Neelie Kroes, vice president of the European Commission, which is responsible for Europe's digital agenda. "Spying is the world's second oldest profession," she said in Bonn. "Let's not be naive–it won't ever stop. We just need to be able to protect ourselves better." –JOHN BLAU



NEW PROBES REPLACE SURGEONS' SENSE OF TOUCH

Laparoscopic pressure sensors make 3-D maps of tumors

Surgeons' best tools for locating tumors inside the body are often their hands. But during minimally invasive surgeries–which can reduce recovery time by days–the ability to examine tissue through touch, called palpation, is lost. Instead, surgeons must manipulate the tissue with long, narrow instruments and rely on visual images from tiny cameras. But engineers in the United States, the United Kingdom, and elsewhere have designed new tools to help restore a surgeon's sense of touch.

The devices, dubbed palpation probes, are designed to be used laparoscopically and can detect changes in the stiffness of tissue. Tumors are harder than normal tissue, so they can be detected with a combination of pressure sensors and spatial positioning measurements. The readings are used to create a three-dimensional stiffness map that shows surgeons the margins of tumors.

A team at Nashville's Vanderbilt University led by biomechatronics engineer Pietro Valdastri showed *IEEE Spectrum* a wireless probe that a surgeon can manipulate in the body with a laparoscopic tool. The small, cylindrical prototype was banged up and wrapped in tape, looking more like something you might find on the floor of your garage than in a surgical suite. But it's what's inside that

DID YOU FEEL THAT? A wireless probe manipulated by a laparoscopic instrument should let surgeons sense tumors by touch.

counts—a pressure sensor, a three-axis accelerometer, a three-axis magnetic field sensor, a battery, and a wireless microcontroller.

It works like this: The capsule's pressure-sensing tip is used to gently indent the tissue. The magnetic field sensor and accelerometer track the depth of the indentation, along with its position relative to a stationary magnet nearby. Each point of contact transmits information about the stiffness of the tissue at that point. Using an algorithm to fill in any unexplored area, the computer creates a 3-D color-coded map that displays the tumors. Valdastri's team has been testing their probe on a pig's liver and on a chunk of synthetic tissue that contains tumorlike lumps.

In the pig liver test, Valdastri's probe was off by just 8 percent in its stiffness measurement. "This new sensor capsule is quite successful in measuring tissue properties," says Robert Howe, a professor of engineering at Harvard University who developed some of the first remote palpation technologies in the early 1990s.

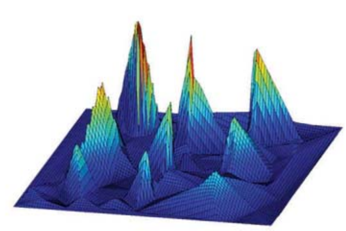
The novelty of Valdastri's probe, compared with previous designs, is in its use of a magnetic field sensor to track its position, according to Russell Taylor, director of the Center for Computer-Integrated Surgical Systems and Technology at Johns Hopkins University, in Baltimore. "It's a very clever way to do it, but it's certainly not the only way to do it," he says.

Another group of researchers, this one based at King's College London and led by robotics expert Kaspar Althoefer, has devised an alternative. Like Valdastri's prototype, Althoefer's system tracks the probe's spatial position, how deeply it indents the tissue, and the reaction force of the tissue. But his design is based on optical fiber technology, and the probe is able to roll over the tissue surface with minimal friction.

Althoefer's probe consists of three surface-profile sensors equally spaced around a spherical indenter. As the probe glides over a tissue surface, the sphere, which floats on a pocket of air, indents the tissue, and a pair of optical fibers measures the indentation. Another set of optical fibers measures the displacement of the three profile sensors, which move up and down with the tissue surface. The three surface sensors and the spherical indenter work jointly to determine the indentation depth and the force with which the tissue pushes back, making a map of the tissue's stiffness. The probe has not yet been tested in an animal.

Valdastri's and Althoefer's work builds upon nearly two decades of remote palpation research. Previous approaches have focused largely on adding touch sensors to conventional surgical instruments. Many of the technologies have been successfully demonstrated, but none have been commercialized.

The challenge is that the costs of the technologies simply outweigh the benefits to surgeons, say researchers. "If you ask surgeons, they'll tell you that they need touch feedback, but then they go and perform a vast range of minimally invasive procedures without it," says Howe. "Touch feedback is in the nice-to-have, not the got-to-have category," he says.



TUMORS ARE TOUGHER: In a stiffness map of a silicone sample, mock tumors stick out. Doctors could generate and use such maps during minimally invasive surgery.

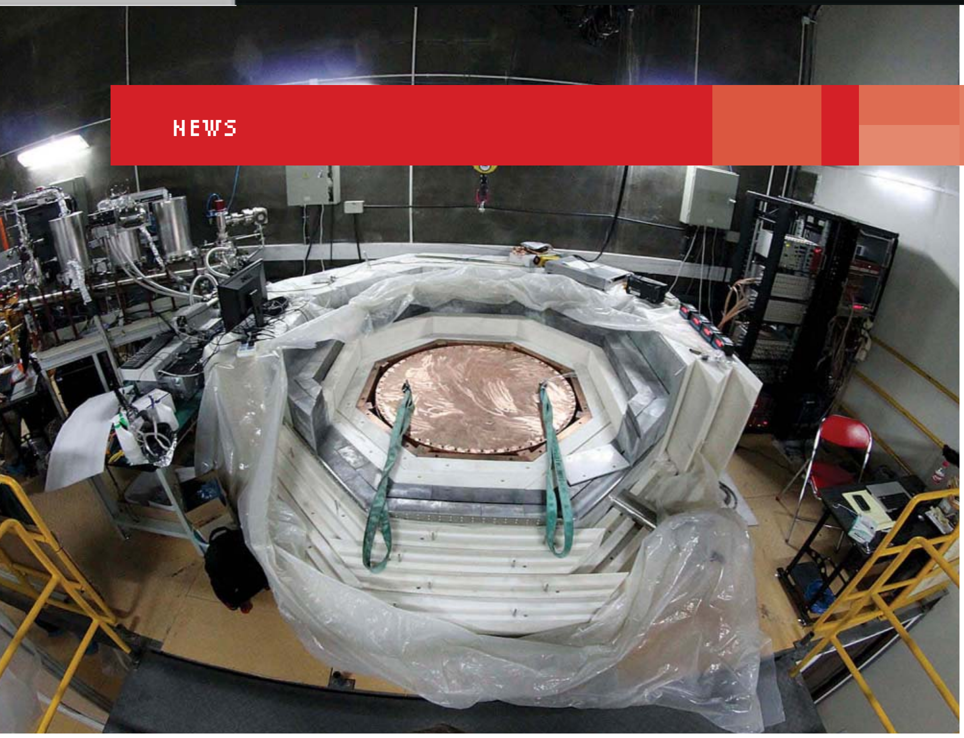
But Valdastri's and Althoefer's probes have some characteristics that might be appealing to surgeons. Because Valdastri's device is wireless, it is less likely to get in the way of other surgical tools, it doesn't require a separate incision, and it may allow surgeons to reach places they can't with a rigid or wired instrument. And because Althoefer's probe glides over the tissue surface with almost no friction, it is less likely to damage the tissue.

But there are also practical hurdles to address in the quest for perfect palpation. Rajni Patel, a robotics researcher at the University of Western Ontario, in Canada, has developed a pressure sensing array to palpate the delicate tissues of the lung. But one major challenge, he says, has been designing an array that can withstand the surgical sterilization process.

Researchers integrating palpation technologies into surgical robots are also still sorting out how to display the many layers of information to the robot's operator. That has been a challenge for biomedical engineer Tim Salcudean at the University of British Columbia, in Vancouver. Using a technique dubbed vibro-elastography, he is generating 3-D elasticity maps by exciting tissue with vibration and measuring the waves produced using an ultrasound elastography probe. The probe is held by a surgical robot, which tracks its position. Keeping track of the elasticity map while performing surgery is a lot of work for the surgeon, he says: "How do we display? Is it an overlay or an adjacent image? How do we simplify controls? It is all very challenging, but seeing *through* the patient is the future of surgery."

It might not be long before feeling around inside the body during surgery is considered old-fashioned. "The new generation of surgeons are not doing a lot of open surgery, so they're not used to palpation," says Salcudean. For those surgeons, computer-generated tissue maps might be all they need to "feel" a tumor. —EMILY WALTZ

TOP: JOHN RUSSELL/VANDERBILT UNIVERSITY; RIGHT: STORM LAB



NEWS

KING UNDER THE MOUNTAIN: In the PandaX experiment, a vat of liquid xenon is stored beneath hundreds of meters of rock. With luck, the isolation will keep things quiet enough to sense signs of dark matter.

THE DEEPEST DARK DETECTOR

China's PandaX project will look for dark matter beneath a marble mountain

In the heart of a mountain in China's Sichuan province, underneath 2400 meters of stone, researchers are powering up the most ambitious effort yet to directly detect some of the strangest stuff in the universe: dark matter. Early this year, the PandaX (Particle and Astrophysical Xenon) experiment will start collecting data in hopes of finding evidence of the elusive particles, thought to constitute more than 80 percent of the matter in the universe.

Physicists first hypothesized the existence of dark matter to explain the "missing mass" problem–the fact that galaxies have a greater gravitational effect than their visible matter can explain. The current theory holds that dark matter is composed of weakly interacting massive particles (WIMPs) that interact with ordinary matter only through gravity and the "weak force," the extremely short-range fundamental force responsible for nuclear decay. If a WIMP bumps directly into the nucleus of an atom of ordinary matter, the theory goes, it might interact with it and cause the emission of other particles, creating visible evidence. Such interactions, however, would be incredibly rare.

Why look for WIMPs under a mountain in China? "I think that one should go to the place where one can do the best experiments," says collaborating researcher Wolfgang Lorenzon, a physics professor at the University of Michigan, in Ann Arbor. Lorenzon explains that in direct dark-matter-detection experiments, it's crucial to shield the detection area from other sources of radiation, which could be mistaken for the WIMP signal. China's new underground lab is the deepest in the world, meaning it's well protected from cosmic radiation; in addition, the rock around it is marble, which is particularly devoid of radioactive materials that could produce false signals. "The big advantage is that PandaX is much cheaper and doesn't need as much shielding material," Lorenzon says.

PandaX is one of several dark-matter-detection projects operating on the same general principle. The experiment looks for interactions within a big tank of xenon, which is cooled to a liquid. If a WIMP does collide with a xenon nucleus, the recoiling nucleus will plow through other xenon atoms and cause the emission of both photons (detectable by a light sensor) and electrons, which will travel through the liquid xenon at a known speed to be detected at the top of the tank. By comparing the two signals, researchers can determine where in the tank the particle interaction occurred. Because the walls of the tank emit some trace radiation themselves, only interactions in the center region of the tank are valid signals.

Ji Xiangdong, the principal investigator of the US $8 million project and the director of the Institute of Nuclear and Particle Physics at Shanghai Jiao Tong University, says one unique feature of PandaX is that it's designed to be scaled up rapidly. If the project's first phase bears fruit, Ji hopes to gain funding for the second phase, which would involve a tank holding 2.4 metric tons of xenon, allowing for an interior target area of about 1 metric ton, which is twice the amount of xenon that will be in use by the end of the first phase of experiments. "If you have that large a volume, you're more likely to see something," Ji says.

That volume would by far exceed the other big dark-matter-detection projects: the Xenon project beneath a mountain in Italy and the Large Underground Xenon (LUX) project at a lab in an abandoned mine in South Dakota. But the field is competitive: The European experiment will also be scaled up to a 1-metric-ton target in the next few years.

The search for the WIMP is a Nobel Prize–worthy pursuit, and Richard Gaitskell, a physics professor at Brown University and a spokesperson for LUX, says he's pleased to see another entrant in the field. "I'm excited about seeing China developing a fundamental physics program," says Gaitskell. "What we have to wait and see [about] is the degree to which the experiment can come up to speed on multiple fronts: cryogenics, shielding, internal radioactivity, and so on."

With PandaX's first results expected this year, researchers will soon know if the detector works as planned. If so, WIMPs will have one less place to hide. –ELIZA STRICKLAND

SCOTT STEPHENSON

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RESOURCES

35.1

THE AVERAGE NUMBER OF HOURS U.S. VIEWERS SPEND WATCHING TRADITIONAL TELEVISION PER WEEK, ACCORDING TO NIELSEN

BEBETO MATTHEWS/AP PHOTO

CHET KANOJIA THE FOUNDER OF THE EMBATTLED START-UP AEREO TAKES LIVE TV TO THE CLOUD

RESOURCES_CAREERS

Few start-up founders dream of going to court. But Chet Kanojia had a feeling that's where he was headed. When it came time to launch his TV streaming service Aereo, Kanojia says he and his New York City–based team spent about six months explaining the technology to media executives. They'd hoped to find broadcast industry partners. But, he says, "the industry doesn't work that way. The industry first litigates, then tries to go to Congress, and then when all fails, then they actually do business." So he wasn't surprised when, within a month of Aereo's February 2012 debut in New York City, a consortium that included major U.S. broadcasters such as ABC, CBS, NBC, and Fox filed suit, alleging that Aereo was redistributing copyrighted material. ● Kanojia might be more inclined to take on large, multibillion-dollar media conglomerates than most. He's seen firsthand how fast changes in media consumption can happen. It was only in the mid-1980s, when he was a teenager living in Bhopal, India, that his family got a color TV, which picked up just a few hours of programming per day. But by the early '90s, they were watching cable television. ● Bhopal is perhaps best known for the Union Carbide disaster there in 1984: Kanojia was pulled out of school to help swap out oxygen tanks for those poisoned by gas. After earning a bachelor's in mechanical engineering nearby at the National Institute of Technology, he completed a master's in computer systems engineering at Boston's Northeastern University. Eager to join the business world, he abandoned his Ph.D. program to join a small product development firm in Massachusetts, before going on to found his first company, Navic Networks, in 2000. ● Navic, which was acquired by Microsoft in 2008, aimed to help cable television companies make the most of the data their set-top boxes collected for purposes such as spectrum planning and targeted advertising. It provided the seed of inspiration for Aereo. ▸

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"We were watching all of the data, and it was sort of obvious to us that there was a huge imbalance," he says. People pay for bundles that contain hundreds of channels, he says, "but they typically only watch seven or eight of them." Some 50 percent of the time, he says, cable viewers are watching network television, which is broadcast free of charge. And as for the other 50 percent of the time, with the rise of online video services such as Netflix and iTunes, "there's absolutely no use for that bajillion-channel universe," says Kanojia.

Aereo's approach is simple: Pick up free television signals over the airwaves and send them to a cloud-based DVR that can store video and stream it to computers, phones, and tablets—for a fee. The signals are picked up by tiny, tunable copper antennas—each about the size of a postage stamp—which are slotted by the thousands into modular racks. Customers can rent one of those antennas for US $8 a month.

Because each customer rents his or her own antenna, the company argues, the process does not conflict with laws that regulate rebroadcasting (and which ensure that broadcast networks get hefty fees from cable companies for the right to transmit network programs to cable subscribers). For the moment, the courts are in agreement. Aereo won the initial lawsuit brought against the company by broadcasters as well as an appeal in April and is in the process of expanding to dozens of other U.S. cities. But the battle will now go to the U.S. Supreme Court.

Is Kanojia afraid he'll be branded as the man who killed the Disney Channel, or other cable- and satellite-only channels? Perhaps not Disney, he says, but "the man who killed the bundle? Sure, I hope."

—RACHEL COURTLAND

THE 3-D VIEW FROM ABOVE

FLY A REMOTE-CONTROLLED PLANE WITH STEREOSCOPIC VISION

ZALMAN JOFFE

THE GAMING WORLD MAY SOON GET A SHAKE-UP WITH the introduction of the Oculus Rift, a 3-D head-mounted display that promises to be compact, comfortable, and reasonably priced. Reading about the DIY origins of this gadget got me wondering how hard it would be to cobble together something similar. Because I'm not a gamer, though, I didn't immediately start investigating the possibility. Then I started to wonder whether a 3-D display could enhance a pastime I *do* enjoy—flying radio-controlled model airplanes outfitted with video cameras so they can be piloted in a mode known as first-person view (FPV). ● I soon discovered a company offering this very thing through an Indiegogo campaign. The folks at EMR Laboratories, in Waterloo, Ont., Canada, have come up with a device they call Transporter3D. It can accept two analog video signals and combine them into a single digital output that can be displayed in 3-D on the Oculus Rift. Combined with EMR Laboratories' stereo video camera, which goes by the much less evocative name 3D Cam FPV, the Transporter3D can provide model-aircraft owners with stereoscopic FPV capabilities. ● All this seemed intriguing, but it wasn't clear to me that a sense of depth would add significantly to the fun of FPV flying. And I didn't want to sink the US $1000 or so it would cost to purchase the 3D Cam FPV, the Transporter3D, and an Oculus Rift developer kit to find out.

So to test the waters, I decided to cobble together a 3-D FPV setup on the cheap. In the end, I was able to do it for less than $250 in parts, although I don't suppose the results I obtained were as pleasing as those you could get using an Oculus Rift with the EMR Laboratories' gear.

Outfitting a model airplane with stereo vision was straightforward, if a little ungainly: I simply bought two identical cameras and two 5.8-gigahertz video transmitters and mounted them to the front of the plane. (Important note: To operate these transmitters legally in the United States, I needed my amateur radio license, so check your national regulations.) I attached the cameras to a home-brew pan-and-tilt mechanism, setting the separation between the cameras about equal to the distance between most people's eyeballs.

The real challenge was how to view the two video streams stereoscopically on the ground. My first instinct was to build a mirror stereoscope along the lines of the equipment used to view aerial photos. I went ahead and did that, using four front-surface mirrors I had bought for a song from Surplus Shed and two 7-inch LCD screens that I purchased for $10 apiece on eBay.

These displays, originally intended for viewing movies from the backseat of a car, had been built into automobile headrests, but they were easy to extract. They offered decent resolution (640 by 480 pixels) and a 4:3 aspect ratio, which matched my video cameras.

But once I had my stereoscope jiggered together, I was disappointed. The long optical path created by the four mirrors made for a lot of distance between my eyes and the screens. This significantly reduced the amount of coverage across my field of view, so the setup didn't feel at all immersive.

I went back to the drawing board and, after some poking around, discovered that I could set up LCD screens to flip the video output, either from left to right or up and down. So I redesigned my viewer, taking advantage of the LCD controls to flip the video images and eliminate two mirrors from my design. The remaining two mirrors, one in front of each eye, then flopped the views back to normal. This tactic reduced the optical distance between my eyes and the screens so that they covered much more of my field of view.

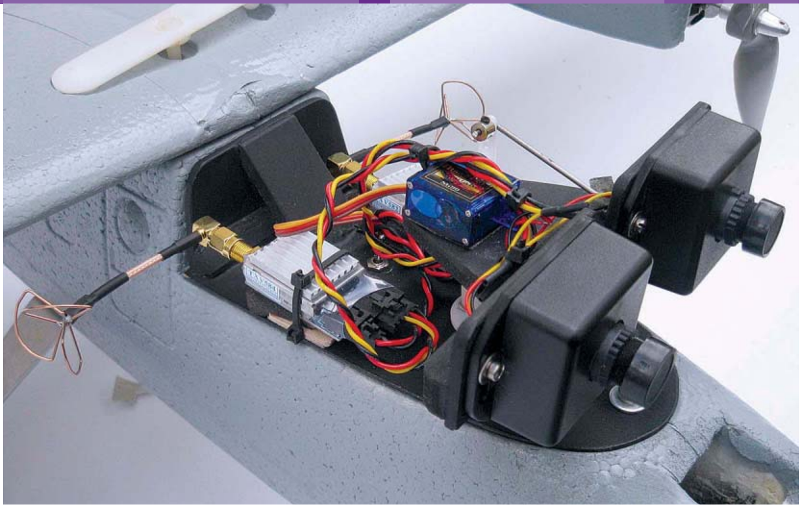
The rub was that the screens were now too close to focus on, especially for someone suffering middle-age farsightedness. The solution was to do exactly what's done in the Oculus Rift: add lenses. At first I tried using the strongest reading glasses I could buy at the drugstore, but that wasn't adequate. A couple of 3x magnifying glasses ($4 each from Amazon) did the trick, however.

My viewer looks a bit like one of those early 20th-century cabinet stereoscopes that allowed users to view stereo-image pairs in 3-D. Had I made it out of wood with a nice rubbed finish, it might have resembled a genuine antique. But I just slapped it together using black foam-core board, polyethylene foam, and duct tape.

It's probably a good thing that I hadn't invested too much time in the aesthetics, because flying in FPV in 3-D with this viewer turned out to be disappointing compared with watching 2-D video. Although the perception of depth held up for surprisingly distant objects, the limited resolution of my LCD screens, combined with the magnifiers needed to view them, made me feel as though I was looking through a screen door, with the real world now resembling one of the blocky landscapes of *Minecraft*.

This wasn't a surprise. Indeed, in reading about the Oculus Rift online, I noticed lots of discussion about "the screen-door effect" and efforts to eliminate it by adding an optically diffusive material in front of its display. The Oculus Rift developer kit provides 640 by 800 pixels per eye, which is better than my home-brew viewer, but the resolution is still too low for universal comfort, it seems.

The consumer version of the Oculus Rift will offer better resolution than the developer prototype, although it's impossible to know right now whether it will be enough to eliminate the screen-door effect entirely. To my mind, making the world look pixelated takes more away from the experience of FPV flying than the 3-D effect adds. So for the moment, for my FPV flying, I prefer a world that's flat. —**DAVID SCHNEIDER**



AIR SHOW: I mounted two video cameras on my plane to provide stereoscopic vision, each with its own transmitter [top]. Images were displayed on two screens in the headset [left] and then brought via mirrors to the eyepieces [above].

DAVID SCHNEIDER (3)

RESOURCES_INNOVATION

Q&A: EDGAR LOBATON
MAPPING DISASTER SITES WITH CYBORG INSECTS

A FIRST RESPONDER? Robust insects, like this cockroach, could have circuit boards fitted to their backs, enabling them to map disaster sites.

AS ANYONE WHO'S TRIED TO SQUASH A COCKROACH knows, the insects are adept at searching out nooks and crannies. Edgar Lobaton and his colleagues at North Carolina State University, in Raleigh, are finding ways to turn this natural ability to the benefit of disaster victims. The team is developing software that can create maps of collapsed buildings using data gathered by tiny circuit boards that have been attached to cockroaches before they're released into the buildings. Lobaton spoke with Senior Editor Stephen Cass for *IEEE Spectrum*'s "Techwise Conversations" podcast about how this technology could guide rescuers to passages and other voids in the rubble.

Stephen Cass: People generally don't like it when a cockroach sidles up to them. Why not just build little robots for mapping?
Edgar Lobaton: Nature has already done a great job of making cockroaches very robust. Why not take advantage of that? As well as the cockroaches' "hardware," they come preprogrammed with behavior that tells them how to survive and explore a particular environment. So those are some of the things we're trying to take advantage of in trying to use cockroaches as a platform for the exploration and mapping of environments. We're trying to exploit the fact that they have their own natural behavior, their own random motion, random walks, and then exploit that—tell them to move randomly most of the time. And then once in a while we'll tell them, okay, now it's time to switch your behavior so you can do more-efficient exploration.

S.C.: So on the hardware side, how do you switch the roaches from wall-following mode to random-walk mode and back again?
E.L.: They have these antennae, which they use for their sensing quite a bit. What my collaborator is doing is clipping the antennae and then attaching electrodes directly to the cockroaches. Then we can tell them there is nothing in the environment, there is nothing to worry about; they can do this random motion that they usually do. Or otherwise we can tell them there is something maybe that is coming from behind them. At that point, the cockroaches would try to look for some sort of shelter.

S.C.: Are there any ethical issues involved in turning a cockroach into a cyborg?
E.L. The consensus is, based on the biology of the insects, that they don't actually feel pain, so there's not much of this ethical concern.

S.C.: How does a swarm of these biobots map an area?
E.L.: You release them from a single location. They're going to start exploring all over the area. There's not going to be a GPS signal to tell them where they are, and you're not going to have very accurate odometry information, because they'll be going through very rough terrain. We're relying on the simplest type of information you can imagine, which is basically keeping track of these agents meeting each other.

S.C.: So what kind of map can you extract from this data?
E.L.: We're used to very accurate maps, such as of the floor plan of a building, for instance. With the cockroaches, we're coming up with a sketch of what the environment looks like, but it still gives us useful information to be able to pinpoint where somebody may be trapped, such as how to get from location A to location B by following some particular type of landmarks, like a narrow passage.

These questions and answers have been edited and condensed. To read or listen to the full interview, visit http://spectrum.ieee.org/lobaton0214

ISTOCKPHOTO

PHOTO-ILLUSTRATION BY **Gluekit**

ALL HAIL NIKOLA TESLA!

ONE OF TODAY'S BIGGEST TECH SUPERSTARS IS A SERBIAN-AMERICAN ENGINEER WHO'S BEEN DEAD FOR 70 YEARS

TEKLA S. PERRY

PONDERING THE FUTURE: Underneath the statue of the man who made AC power practical, a time capsule contains cards with predictions of what the next decades will bring.

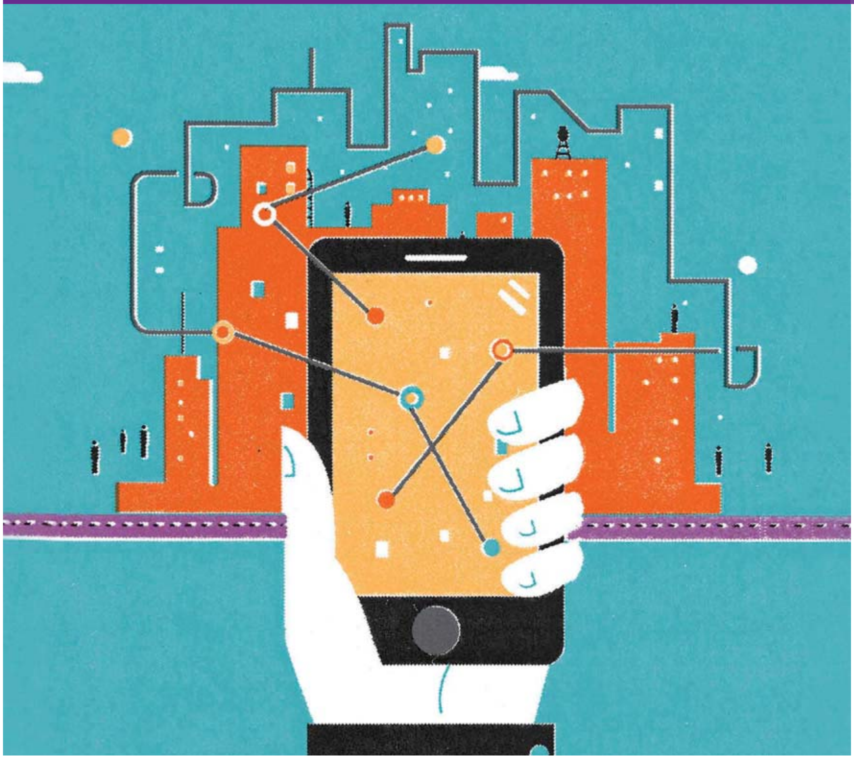
THIS PAST DECEMBER, UNDER A CRISP, BLUE California sky, geeks of all sorts gathered to honor an inventor they believe should be the symbol of Silicon Valley. They were in Palo Alto for the dedication of a statue to Nikola Tesla, the prolific Serbian-born inventor and engineer who lived between 1856 and 1943 and whose life and work is the subject of a wave of revived interest. Tesla's new fans say he is a special figure, not just for the countless advances he made in developing alternating current, wireless energy, wireless communications, and more, but because of his modesty; they believe he was far more interested in moving society forward than in accumulating wealth.

In May 2013, one Tesla fan, Dorrian Porter, launched a Kickstarter campaign to create a tribute to Tesla to stand in Silicon Valley, in the belief that the inventor should be a symbol for the valley's entrepreneurial spirit. The campaign sought US $123 000 and raised $127 260 from 722 supporters, including an anonymous $20 000 donation.

The statue, designed by artist Terry Guyer, rests on land offered by local building owner Harold Hobach. It contains a time capsule, to be opened in 30 years, and a free Wi-Fi hot spot. Greg Leando, a local banker, says he came because "Tesla is an inspiration to a lot of young entrepreneurs. We are at the epicenter of technology and innovation, so it is a fitting tribute."

But the Silicon Valley statue isn't the only marker of renewed interest in Tesla: In September, a monument went up at the nascent Tesla Science Center at Wardenclyffe. This Shoreham, N.Y., location is the site of Tesla's Wardenclyffe Laboratory, which in the early years of the 20th century featured a steampunk-esque tower intended for wireless electrical power transmission experiments. The laboratory buildings fell into disuse, and the land was in danger of being commercially developed until an earlier crowdfunded campaign was launched in August 2012. Led by cartoonist Matthew Inman, who has created a number of popular online infocomics about Tesla on his website Theoatmeal.com, the campaign raised $1.3 million, enough to buy the land and start work on cleaning it up and creating a museum at the site. —**TEKLA S. PERRY**

A version of this article appeared on IEEE Spectrum's *Tech Talk blog in December.*



THE CITY AS COMPUTER

WALKING AROUND A METROPOLIS WILL NEVER BE THE SAME

We want our tools to sing of not just productivity but of our love of curiosity, the joy of wonderment, and the freshness of the unknown. **—Eric Paulos, *"Manifesto of Open Disruption and Participation"***

IN HIS ESSAY "Walking in the City," the French scholar Michel de Certeau talks about the "invisible identities of the visible." He is talking specifically about the memories and personal narratives associated with a location. Until recently, this information was only accessible one-to-one–that is, by talking to people who had knowledge of a place. • But what if that data became one-to-many, or even many-to-many, and easily accessible via some sort of street-level interface that could be accessed manually, or wirelessly using a smartphone? This is essentially the idea behind **urban computing**, where the city itself becomes a kind of distributed computer. The pedestrian is the moving cursor; neighborhoods, buildings, and street objects become the interface; and the smartphone is used to "click" or "tap" that interface. In the same way that a computer, mouse, and interface are required to operate a Web browser to surf sites, the equivalent components of **street computing** create a **reality browser** that enables the city dweller to "surf" urban objects. On a broader level, the collection, storage, and distribution of the data related to a city and its objects is known as **urban informatics** (described by one technologist as "a city that talks back to you"). • Smartphone in hand, what can the modern-day flaneur expect to find in this newly digitized urban environment? First, thanks to the prevalence of GPS data, *wayfinding* is giving way (so to speak) to **wayshowing**, interfaces that provide specific directions from here to there, and to **social navigation**, getting around with the help of others (avoiding traffic, for example) and then checking in with your friends when you get there. Similarly, our urban gadabout might take advantage of **use-someplace** technologies such as *augmented reality*, where physical space is overlaid with virtual data. A good example is Streetmuseum, a Museum of London app that can overlay an archive photo of a street scene onto the same scene as shown through your smartphone's camera. Beyond augmented reality is **amplified reality**, where extra data is built into an object from the get-go. For example, the embedding of radio-frequency identification or near-field communication technologies in street objects enables the creation of **locative media** (also called **location-based media**). These **situated technologies** contain data about a specific location, which is then beamed to devices as they come within range, an exchange known as a **situated interaction**. An example is the **sound garden**, where designers assign sounds to public places, which users can then listen to using Wi-Fi-enabled devices.

There is, sadly, the ever-present danger that advertisers and hucksters will take advantage of these technologies to turn the city into a giant billboard. But to the technologists and social scientists at the forefront of urban computing, the goal is enhanced civic engagement. To that end, where once the ideal of pervasive computing was to create seamless, unnoticeable technology, today's urban computing designers want to build **seamful** interfaces, whose visibility encourages users to interact directly with systems. **Curatorial media** allow for **urban data curation**, the careful collection of stories–histories as well as facts and figures–using technologies called **urban annotation systems**. Since data are both curated and disseminated in such systems, this is known as **read/write urbanism**.

Is the urban computer a good thing? Well, it's certainly an *inevitable* thing, so I wouldn't waste too much breath complaining about it. Think about a regular PC: You can turn it off, or you can use it for fun or for productivity. The urban computer is no different. You can ignore it (turning a city off is problematic), or you can use it to become a more attentive, engaged, and concerned citizen. It's a tool. Make it sing. ■

ILLUSTRATION BY Oliver Munday

Snapping Up

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In January 2012, Kodak filed for Chapter 11 bankruptcy protection, having succumbed to a digital revolution in photography that it had helped to start. But the company's managers still hoped to escape from bankruptcy and have another shot at greatness by selling part of a portfolio of patents that experts valued as high as US $4.5 billion.

Eleven months later, those roughly 1700 patents (together with 655 patent applications) sold for just $94 million–less than the licensing fees Kodak had collected in its worst-ever year in recent history. What's more, the company licensed its remaining 20 000 patents to a dozen leading technology companies for only $433 million, severely restricting future earnings from them.

Without its anticipated multibillion-dollar payoff, the company was forced to hand over its iconic photographic film and paper businesses, as well as potentially lucrative new technologies like digital printing kiosks, to a spin-off owned by its U.K. pension fund. In September 2013, Kodak finally limped out of bankruptcy, a shadow of its former self. The following month, Standard & Poor's Ratings Services assigned the slimmed-down Kodak a B- for corporate credit–a junk-grade rating.

So what exactly happened? Did the consortium of firms that bought the Kodak patents simply make a killer deal? Or were the patents overvalued to start with? In either case, how could such seemingly precious assets lose 95 percent of their value in under a year?

For virtually all of the 20th century, Eastman Kodak Co. dominated photography. It produced the inexpensive Brownie camera, made 9 out of 10 rolls of film bought in America, and gave the world billions of colorful "Kodak moments." In 1969, Kodak built a stereoscopic camera for the Apollo 11 astronauts, and six years later Kodak engineer Steven Sasson invented the world's first digital camera.

But there was something wrong with this picture. Kodak executives saw digital as a threat to its film business. And its chief intellectual property officer, Timothy Lynch, says, "[we] basically told Sasson to take that box and go away; we don't ever want to see you again." A complacent Kodak also underestimated competition from Fuji's color films. In the 2000s, digital cameras flooded in from Asia, and first camera phones and then smartphones decimated Kodak's

Kodak

THE SHOCKING PATENT DEAL THAT NEARLY SANK A TECHNOLOGY GIANT

By Mark Harris

A FAMILY POSE shows Kodak cameras from 1888 to 1999 [above left], spanning box models, folding cameras, Instamatics, and a digital camera in the front. Kodachrome [above right] helped the company dominate the U.S. market for film for many decades. Steven Sasson [opposite left] invented the digital camera at Kodak in 1975, but nervous executives told him to "take that box and go away." Later Kodak embraced digital systems, notably the Professional Digital Camera System [opposite right], launched in 1980 and attached to a Nikon film single-lens reflex camera. It needed a separate storage unit to hold its 1.3-megapixel images.

point-and-shoot business. By the time it filed for Chapter 11 in 2012, Kodak had reorganized and shed tens of thousands of jobs.

Even then, Kodak hoped that by selling some patents it could recover from bankruptcy and get on with reinventing itself as a commercial and packaging printing company. Throughout decades of turmoil, Kodak had continued to innovate, spending up to $500 million annually on R&D. The company developed the first megapixel image sensor, which went into Apple's groundbreaking QuickTake digital camera, and it came out with the first cameras with OLED screens and built-in Wi-Fi. By 2012, Kodak had accumulated 22 000 patents and other intellectual property covering 160 countries. From 2003 to 2011, licensing that IP to other companies had earned Kodak over $3 billion.

The signs for a sale looked good. The market for IP was sky high. Record-breaking deals in 2011 included Apple, Microsoft, and Research in Motion paying $4.5 billion for Nortel's portfolio of 6000 wireless communication patents, and Google's purchase of Motorola Mobility's cellphone IP (and the company along with it) for $12.5 billion. The consultants behind the Nortel deal, 284 Partners, reckoned that a set of 1700 Kodak imaging and printing patents could fetch up to $2.6 billion on the open market; three other firms valued them at between $1.8 billion and $4.5 billion. Kodak officials had every reason to believe their plan was the right one.

In the United States, trading in patents goes back more than two centuries, to when America's founding fathers' system made it straightforward to register, sell, and buy intellectual property.

Two-thirds of the most famous U.S. inventors of the early 19th century sold or licensed their patents, and legal disputes were common, according to research by the economists Kenneth L. Sokoloff and B. Zorina Khan. The "sewing machine wars" of the 1850s saw up to twice as much litigation, proportionally, as the modern struggle for smartphone supremacy. Dozens of individuals and companies struggled to perfect automated sewing technology, with the result that hundreds of overlapping patents were granted. And when Isaac Singer settled a high-profile patent suit with rival inventor Elias Howe, litigation threatened to rip the nascent industry apart at the seams. Large manufacturers were sued by individuals exercising key patents–what some people today call patent trolls. (More-polite terms include patent assertion entities (PAEs) and non-practicing entities (NPEs), so called because they do not produce goods or services subject to countersuits or injunctions.)

Although the rough and tumble of patent trading is nothing new, the stakes have risen considerably. Damage awards from IP infringement suits have spiraled upward; in 2012, for instance, Samsung and chipmaker Marvell each faced judgments of over $1 billion. "Massive awards are new," says Robin Feldman, a law professor at the University of California Hastings College of Law. "The patent system is allowing rights holders to bargain for compensation far above the value of the right. It's become a gold rush, and there is an extraordinary level of speculation in the market."

Some experts link that speculation to the arrival of patent aggregators, and specifically Intellectual Ventures. Founded in 2000 by ex-Microsoft CTO Nathan Myhrvold, Intellectual Ventures has used over $6 billion of its investors' money to acquire tens of thousands of patents. The firm then either licenses the IP or sues companies that it claims are infringing on those patents–a process known as monetization.

"We were early and helped create the ecosystem around patent buying," says Jeremy Salesin, vice president of acquisitions at Intellectual Ventures. "There has since grown up a network of buyers and brokers. The result is that the flow of patents is stronger and more constant than years ago."

Where once patents were traded between companies largely as a hedge against litiga-

PREVIOUS PAGES, LEFT: EDUARDO MUNOZ/REUTERS; RIGHT: ISTOCKPHOTO; THIS PAGE, LEFT: SSPL/GETTY IMAGES; RIGHT: DAVID DUPREY/AP PHOTO

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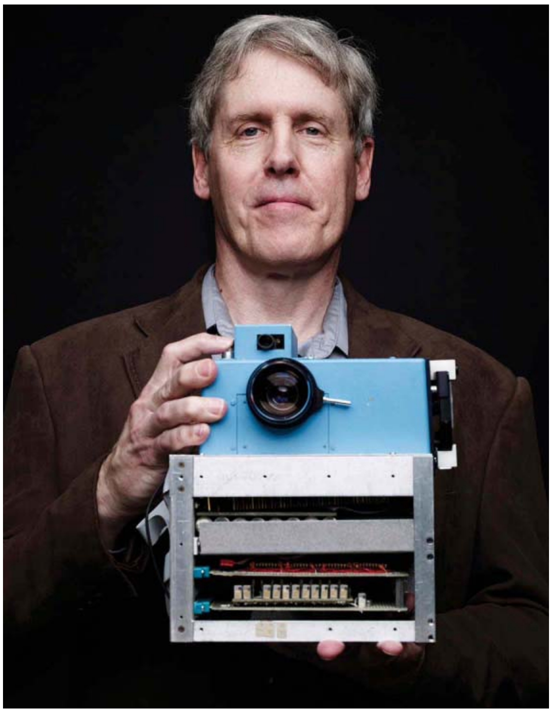


tion, 50 to 60 percent of portfolios are now sold to PAEs. Some PAEs, like Intellectual Ventures, go after big manufacturers for large sums of money. Others target smaller companies like podcasters with a deluge of threatening (and sometimes misleading) demand letters; small business owners anxious to avoid expensive litigation will often settle. One such campaign sent over 8000 letters. A very few, like patent aggregator RPX, claim to use their patents only defensively, creating a pool of intellectual property for operating companies to dip into when sued. (A pool like this, called the Sewing Machine Combination, finally brought the sewing machine wars to a close in 1856.)

IP experts thought it unlikely that a portfolio as extensive and lucrative as Kodak's would end up with a PAE, even one as well funded as Intellectual Ventures. Putting an exact value on it, however, was a tricky business. "Patents are unique and idiosyncratic assets," says Robert Heath, senior vice president for corporate development at RPX. For example, companies wishing to enter an established market or boost their market share are often willing to pay a premium, as Google and Apple did with smartphone patents in 2011. Manufacturers or aggregators already sitting on a healthy portfolio, on the other hand, might pass up otherwise attractive patents.

Michael Lasinski's firm, 284 Partners, was hired by Kodak in July 2011 to value 1730 of its patents. With so many variables to consider, he favored a purely financial approach. "You roll up your sleeves and create a business plan around the IP," he says.

Specifically, 284 Partners used what investors call a discounted cash-flow analysis, which estimated the expected income from monetizing Kodak's patents through licensing and, if necessary, legal action. Just as it had done for the Nortel portfolio, 284 Partners interviewed Kodak managers, read claims and court filings, reviewed previous licenses and projections, checked royalty rates, and examined key patents. Lasinski says his company also adjusted revenue expectations to reflect the risks inherent in licensing the IP.

Ultimately, it projected cash flows from the patents of \$3.07 billion from 2012 to 2020, giving the portfolio a present value of \$2.2 billion to \$2.6 billion. Lasinski thought that estimate "very conservative" given Kodak's existing licensing and future plans.

With the estimate from 284 Partners in hand, Kodak began shopping its patents. Just days before it filed for Chapter 11, it also filed a flurry of lawsuits, alleging patent infringement against Apple, Fujifilm, HTC, and Samsung. Kodak already had an outstanding complaint at the United States International Trade Commission (USITC) against Apple and RIM. Both actions should have helped to move the Kodak IP: Selling patents to alleged infringers is a quick way to make such lawsuits disappear.

But the technology companies didn't bite. Instead, Apple swiftly countersued Kodak for infringement. It also tried to halt the sale of 13 Kodak patents that had been filed during the two companies' joint development of the QuickTake camera, alleging they belonged to Apple and a spin-off company called FlashPoint. Kodak complained to the court, "Apple and FlashPoint are seeking to benefit from Kodak's difficult financial position, which will be exacerbated if [we] cannot obtain fair value for the patents."

The truth was that Kodak now desperately needed money. Securing a restructuring loan of nearly \$1 billion depended on the patent sale, and anything hindering that would put the future of the company in jeopardy. Fortunately, the bankruptcy court sided with Kodak against Apple and allowed the sale to continue. By early July 2012, Kodak had lined up around 20 potential bidders for an auction of the patents.

Then disaster struck. In late July, barely two weeks before the auction was due to commence, the USITC made its final ruling

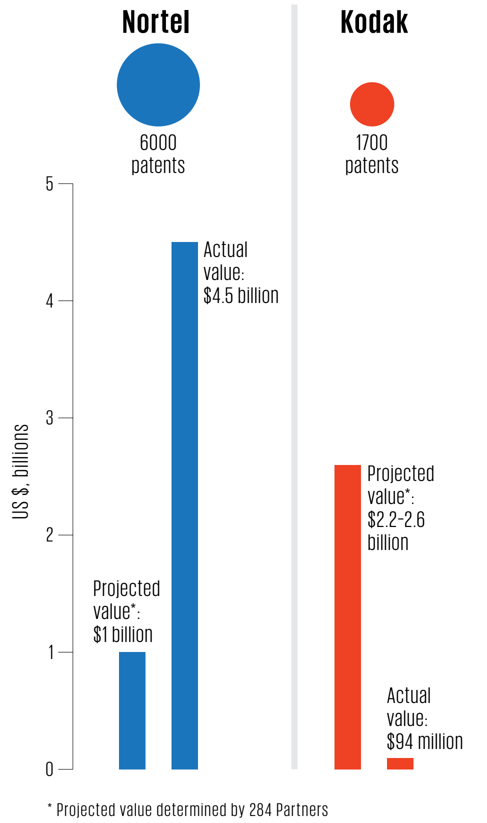
LEFT: DAVID YELLEN; RIGHT: SSPL/GETTY IMAGES in Kodak's case against Apple and RIM. It found the Kodak patent in question, covering a way of capturing still photos while previewing motion images, to be invalid. That one patent, nicknamed "218" for the last three digits of its assignment number, had previously been used to secure licensing deals with LG and Samsung for a reported $414 million and $550 million, respectively. (Annoyingly for LG and Samsung, such deals are usually final, with no recourse should the patent later be thrown out.) The USITC decision would not necessarily affect 218's value in domestic litigation, but untangling the mess would take time that Kodak did not have.

"We were floored by that decision," says Kodak's Lynch. "Weeks earlier, the same patent had survived re-exam and came out with absolutely no changes. If we'd had the resources and the financial stability, we would have taken this to the Federal Circuit and gotten it righted...but that's just not the way it works in bankruptcy. You start to lose control of the process and timing and you just have to drive forward. It's a freight train."

Lasinski of 284 Partners still has a nondisclosure agreement in place for the Kodak deal and so can't comment on the particulars. "Speaking generally," he says, "when cash is required quickly and you have to switch a strategy from a certain patent to other patents, that can impact their value." Envision IP, an IP research firm not directly involved in the case, duly reduced its valuation of Kodak's portfolio by around $1 billion, to $1.4 billion at most.

Such reversals of fortune are commonplace in IP litigation. Billion-dollar judgments are regularly overturned on appeal, and even a patent that has held up in court multiple times, like Kodak's 218, can be judged worthless at new proceedings. Part of the problem is that while patent attorneys must hold an engineering or science degree, there are no such requirements for judges or juries, leading to some technically dubious decisions.

A bigger issue, though, goes to the heart of the patent system. "You can't tell at the time of a patent grant precisely what it covers," says Feldman of the University of California. "You're using language that's going to be compared to something that doesn't exist at the time you write it." By



DETERMINING THE VALUE of intellectual property can be very difficult. Nortel's wireless patents raised 450 percent of their presale estimate, Kodak's imaging patents less than 5 percent.

the time an industry grows up around a patent, a decade or more down the road, its text may seem obsolete, absurdly irrelevant, or excessively broad.

Nokia estimates that as many as 250 000 existing patents could apply to smartphones. If each patent added just one cent to the cost of a handset in licensing, the dumbest smartphone would be liable for $2500 in fees. That doesn't happen, in part because of cross licensing of IP between manufacturers but also because most patents are virtually worthless. An estimated 90 percent of patents never earn a direct return, and three-quarters of U.S. patents are abandoned seven years after being issued, when extra fees to keep them in force become due.

Even without 218, Kodak had a wide-ranging and substantial portfolio. And so when the auction opened on 8 August 2012, the company still expected multiple bids above a billion dollars. But when the envelopes were opened, it had received just two offers, the highest of which was reportedly a mere $250 million.

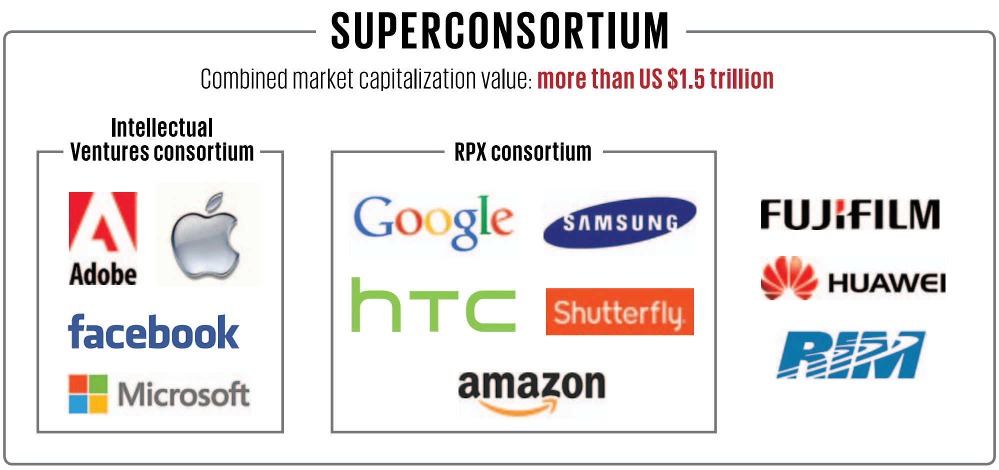
The potential bidders, it turned out, had organized into two camps. In one, Adobe, Apple, Facebook, and Microsoft formed a consortium led by Intellectual Ventures. In the other, RPX mustered Amazon, Google, HTC, Samsung, and the photo-printing website Shutterfly. Each participant in such a consortium gets to keep a share of the patents and a license for the rest. The cost to each is relatively low, and all gain the protective power of the entire portfolio.

"We knew this would be one of the largest deals ever done," says Kenneth Lustig, head of strategic acquisitions at Intellectual Ventures. "It was our conclusion that it was likely a consortium buy, and as a leader in the invention business we felt it was something we should lead."

Kodak balked at the offers. A few hundred million dollars would not be enough to secure the loans it required and might devalue its remaining IP by association. The company extended the auction and then threatened to abandon it altogether. "They did not get the spontaneous bidding war they wanted," says RPX's Heath. "I imagine it was a splash of cold water." The earlier licensing deals with LG and Samsung, he adds, "had reduced the strategic value of the portfolio and...dampened people's enthusiasm."

Negotiations with potential buyers continued into October, but time was running out. If Kodak couldn't complete a deal, its plan to emerge from Chapter 11 would fall through and the company might be split up or shut down. Simply put, Kodak needed more money to survive than either consortium was prepared to pay.

The logical solution was for Intellectual Ventures and RPX to form a superconsortium. And so they did. With the two aggregators at the helm, the consortiums merged and acquired three new members: Fujifilm, Huawei, and RIM. The superconsortium now featured a dozen of the world's big-



KODAK'S ORIGINAL AUCTION for its 1700 imaging and printing patents attracted over 20 possible bidders. However, the strongest purchasers formed two consortia, led by patent aggregators Intellectual Ventures and RPX. Neither consortium's bid was high enough to allow Kodak to escape Chapter 11 bankruptcy. Along with three smaller companies, the consortia then merged into a superconsortium whose members dominate the digital world in the 21st century. Its final bid was successful.

gest technology multinationals, with a combined market capitalization of more than $1.5 trillion (the size of Australia's GDP). Its members reach almost every human being who is online, have software running on 98 percent of all computing devices, and sell half of the world's smartphones.

Back at the negotiating table, the pressure ratcheted up again. In November, Kodak announced that it had secured $793 million in funding from banks and investment funds, on the condition that its patents raised at least $500 million. But that figure was still higher than both previous bids combined. The new, more powerful superconsortium was hardly going to make a worse deal than before. Its members offered an alternative. They would help Kodak cross the magic $500 million barrier, but only in return for the company's family silver: the tens of thousands of Kodak patents that had previously not been on the table. Kodak would also have to agree to drop all legal cases against consortium members and vice versa.

Kodak was up against a wall, its single possible buyer a consortium that included almost everyone who might want what it was selling. Inevitably, a deal was struck. In mid-December, Kodak sold its imaging and printing portfolio and a license to all of its remaining patents to the superconsortium for a total of $527 million. The portfolio itself earned the company just $94 million–about 4 percent of 284 Partners' initial valuation. Although the financial breakdown of the deal is subject to a nondisclosure agreement, the 12 superconsortium members each received licenses to more than 20 000 Kodak patents for an average of $44 million. That's less than one-tenth of what Samsung paid to license just two Kodak patents, including 218, back in 2009.

"Things never play out the way you expect them to," says Kodak's Lynch. "The rights that the consortium wanted, they got. We got what we got because of all the dynamics in that period, which really were quite negative for us."

There's a word for deals like this: "monopsony." It's when a single powerful buyer dictates terms to sellers. Although rarer than a monopoly (where a single seller sets prices), it can lead to outcomes just as inequitable. "From an antitrust perspective, there is always a concern when competitors get together," says Feldman. "There is a temptation to bash everybody who is not in the room with them. At the moment, there are virtually no constraints if parties in the patent market...wish to collude, to divide up the market, to manipulate that market in various ways."

Changes in the U.S. patent system are afoot, with the White House announcing in June 2013 moves to improve the quality of newly issued patents, boost transparency, protect small businesses, and reduce nuisance lawsuits. These moves are unlikely to curb the influence of superconsortiums, aggregators, or PAEs, however. More useful, thinks Feldman, is the Federal Trade Commission's promise to investigate the entire industry of patent monetization. "The FTC can subpoena things shrouded in nondisclosure agreements and require companies to report on what they are doing," Feldman says. "Lack of information is a key issue for regulators and legislators in figuring out what they could do."

RPX for its part insists that the Kodak deal was consistent with antitrust laws. "In bringing this consortium together, we did efficiently what a licensor would have done painstakingly over the next four or five years," says Heath. The winning parties note that the Kodak sale has had little effect on the patent market generally. In fact, Intellectual Ventures, which ended up owning all of Kodak's digital imaging patents, is already licensing them to other companies. "Some would say the Kodak portfolio is heavily licensed, but we really know how to pull it apart and look more closely," says Loria Yeadon, executive vice president of Intellectual Ventures' Invention Investment Fund. "For us, there's significant value remaining in the patents. Kodak also had a lot of [patent] applications it was continuing to file. We have future value in those as well."

Kodak's fire sale shifted decades of intellectual capital, at pennies on the dollar. "There's the concept of people like Kodak, like IBM, like Bell Labs, who invested billions and billions of dollars in R&D and now these new guys come along that haven't done any of that," says Lynch. "It's almost like your kids. At some point you're going to transfer your wealth to your kids. We're in the process of transferring our intellectual property wealth to the new entrants."

There is at least one benefit arising from the Kodak deal. The "patent peace" imposed by the superconsortium should discourage expensive, high-profile courtroom battles in the years ahead–at least in the area of digital imaging. ■

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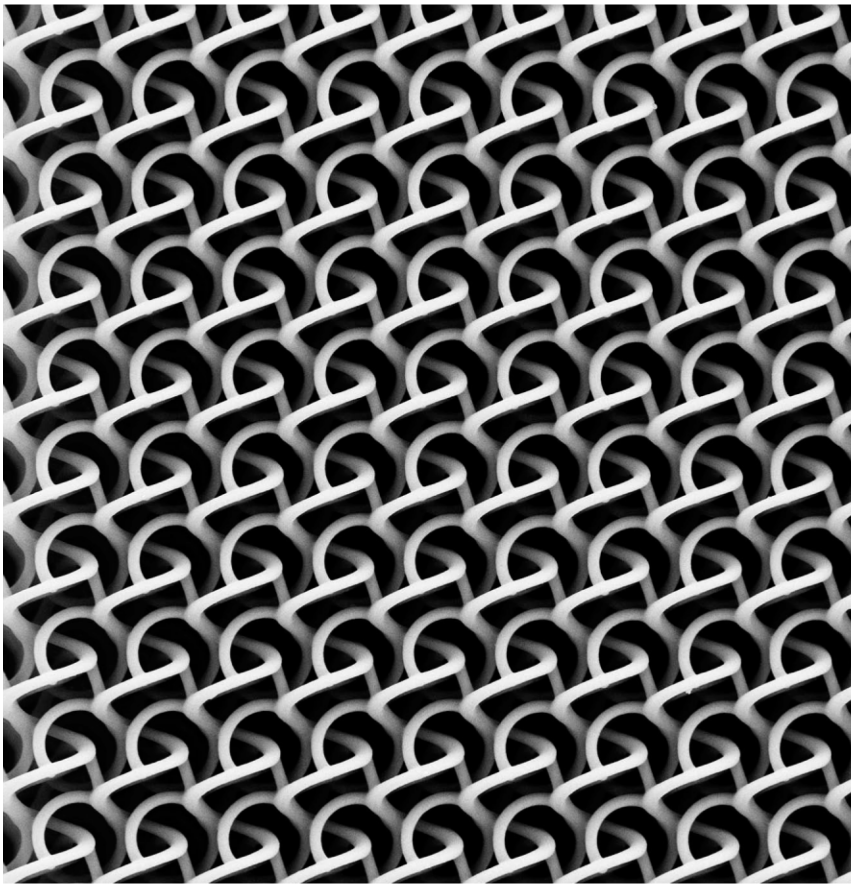

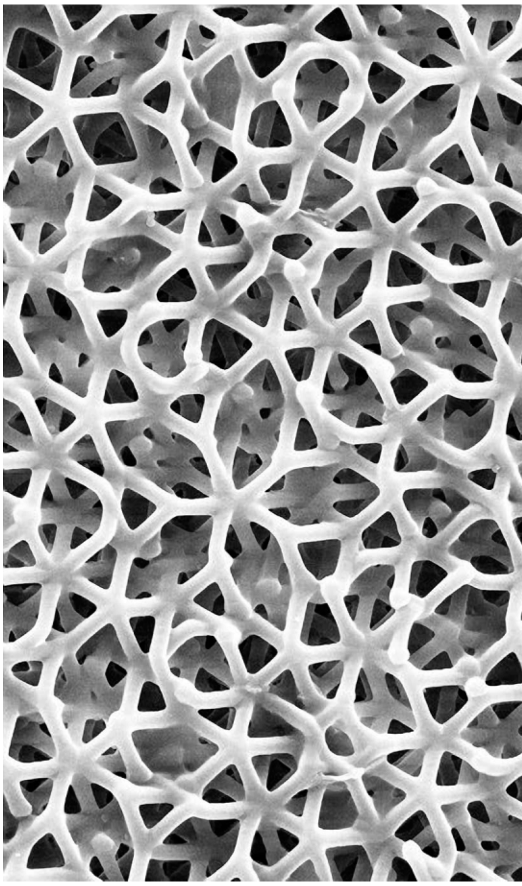

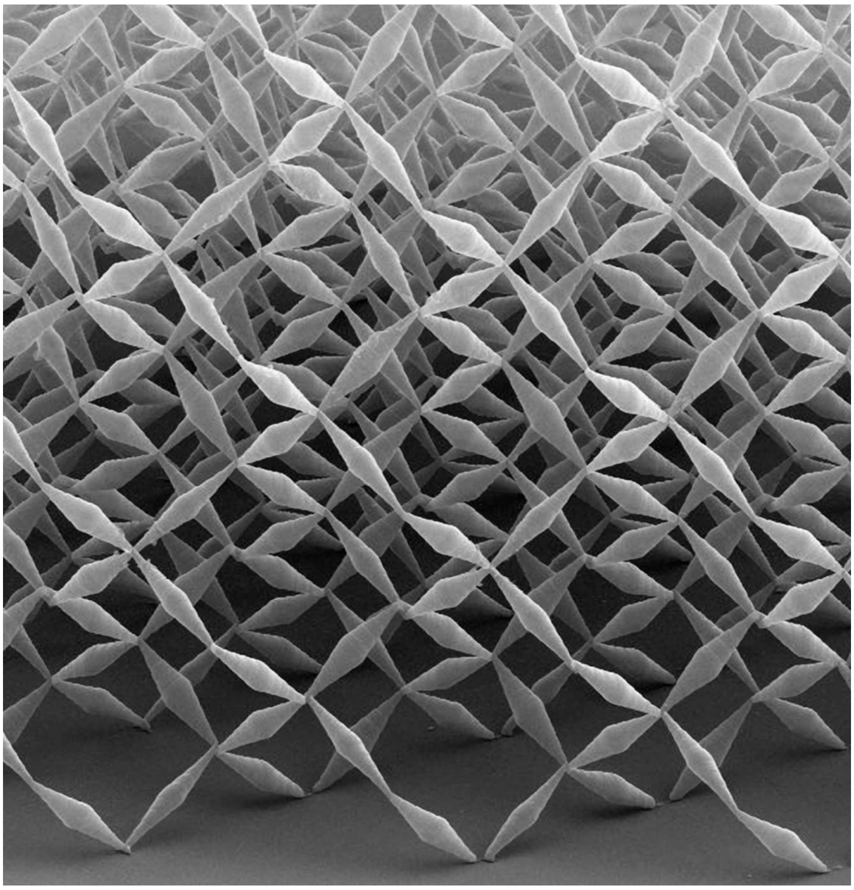

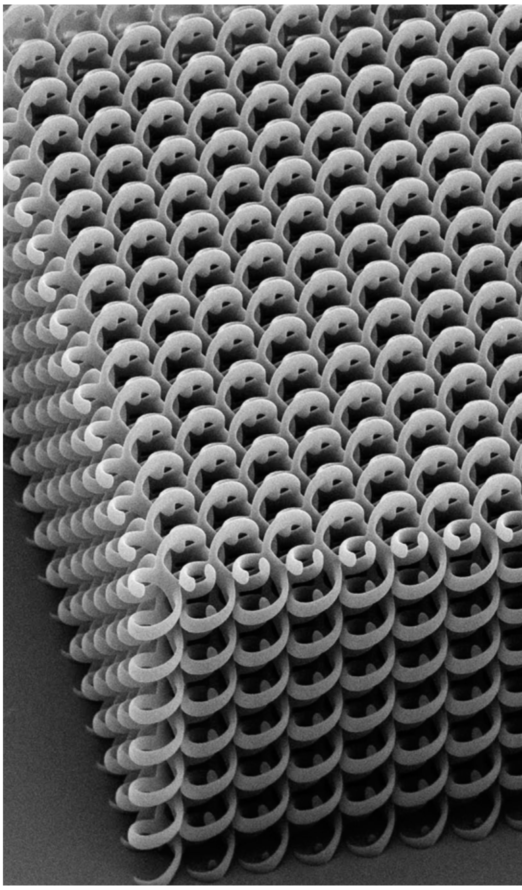

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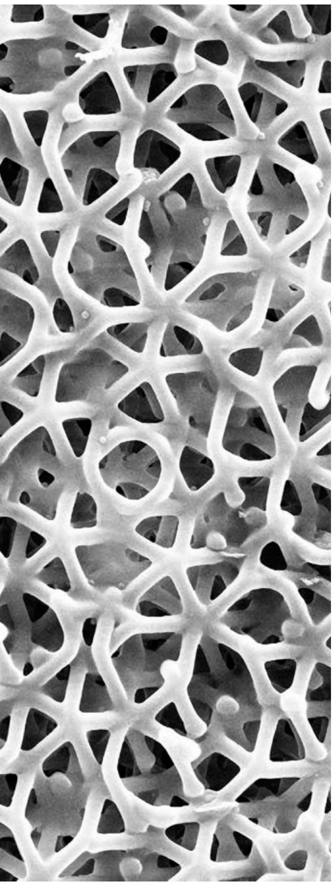
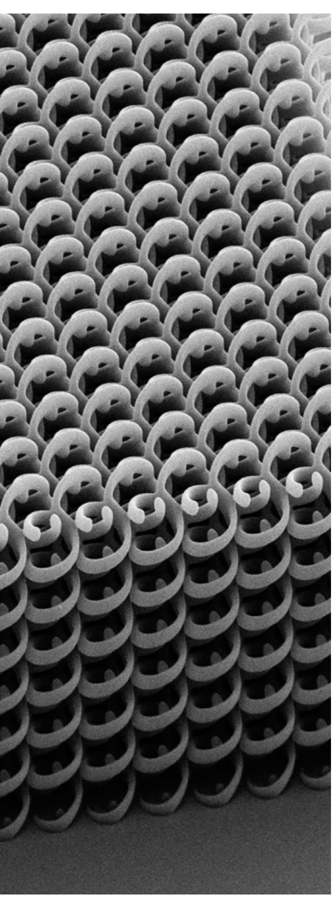




MATTER *MADE* TO ORDER

With laser-sculpted atoms, researchers can build better metamaterials

BY JOACHIM FISCHER, MICHAEL THIEL & MARTIN WEGENER

For a century or more, nearly all technological advances have depended on our ability to produce and manipulate the vast variety of materials that nature has given us. Nowhere is that dependence more evident than in the field of electronics. From a smorgasbord of semiconductors, polymers, and metals, we've been able to create a dazzling array of circuitry that now underpins pretty much every aspect of modern life.

So now imagine what we could do if we weren't limited to the materials found in nature. Researchers have long believed that it would someday be possible to produce artificial materials, or "metamaterials," and that they would bring about some stunning, otherworldly technologies–the sort that have figured in science fiction tales for years. These innovations include invisibility cloaks that could mask the presence of objects or their electromagnetic signatures, "unfeelability cloaks" that could mechanically mask the tactile feel of an object, superlenses that could resolve features too small to be seen with ordinary microscope lenses, and power absorbers that could capture essentially all of the sunlight hitting a solar cell.

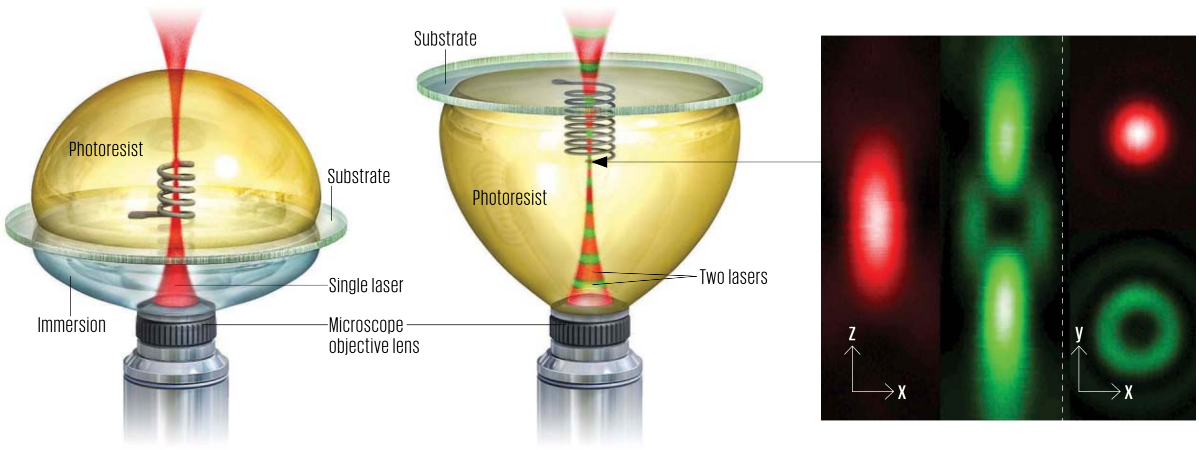
To achieve these advances we'll need better metamaterials, and those are on the way. Metamaterials are made up of "meta-atoms"–small two- or three-dimensional structures made of polymer, dielectric material, or metal. When these structures are arranged in regular, repeating crystals, they can be used to manipulate electromagnetic radiation in new ways. Ultimately, the capabilities of a metamaterial are determined by the size, shape, and quality of these structures. And the technology to fabricate meta-atoms has recently turned a corner.

Over the past few years, research groups around the world have succeeded in developing a way to draw meta-atoms using lasers. The resulting structures can now take on nearly any shape and be stacked in three dimensions in dense, crystal-like arrangements. What's more, they can be made small enough to exhibit unique mechanical and thermal properties and to alter the flow of light in a range of

MADE FROM SCRATCH: Lasers were used to draw the micrometer-scale structures in these metamaterials. Pictured clockwise from top left are a bichiral photonic crystal [top view], a photonic quasicrystal, a bichiral photonic crystal [oblique view], and a pentamode metamaterial.

WRITING THROUGH RESIST

Constructing minute 3-D structures on a microscope



THE TWO-BEAM SOLUTION: A single laser beam shone upward through a microscope objective lens and a glass slide [left] can be used to draw 3-D structures inside a photosensitive compound called photoresist. But two innovations [center] have helped improve the writing process. One is to use two lasers: a red one to excite the photoresist and a green one to de-excite all but a central point so that much finer features can be drawn. The vertical and horizontal cross sections of both beams are shown at right. The process got a second boost from a recently discovered photoresist. The optical properties of this compound can be tuned so that it can also act as the immersion liquid, which carries light from the objective lens. This allows taller structures to be built, because the microscope slide won't get in the way.

wavelengths—including the long-inaccessible visible chunk of the spectrum. Thanks to this microscopic fabrication technology, we can finally see a path beyond the materials nature has provided us into entirely new realms that are limited only by our imaginations.

AS DIVERSE AS NATURAL MATERIALS ARE, they actually have a fairly narrow range of properties. That fact becomes quite evident in the way materials respond to light.

Ordinary atoms, such as silicon and copper, are full of charged particles and typically interact quite strongly with electric fields. But an electromagnetic wave is made up of two pieces: an oscillating electric field and an oscillating magnetic field. And the response of materials to magnetic fields is another story.

For a few quantum mechanical reasons we won't get into here, many atoms do respond to the magnetic component of electromagnetic radiation (this response is what enables, for example, magnetic resonance imaging). But most atoms stop resonating—and thus responding—to the magnetic component of light when incoming radiation has a frequency above about 100 gigahertz, the high-frequency edge of the microwave part of the spectrum. That means, effectively, that conventional materials respond only to the electric part of an electromagnetic wave, particularly at infrared and visible wavelengths.

That might have been the end of the story. But in 1999, physicist John Pendry of Imperial College London and colleagues pointed out that it should be possible to create transparent structures that can manipulate both the electric and magnetic components of light.

To do this, the group devised a metallic ring with a slit cut out in the side. Like any metal loop, this split ring will resist a change in an external magnetic field with an inductance, or L. But because the loop has a gap in it, it will also accumulate charge on each side of that gap, giving the ring a capacitance, or C. The result is an LC circuit. Given an incoming electromagnetic wave with the right frequency, the split ring will respond with an oscillating current, and thus an oscillating magnetic field, of its own. The smaller the ring, the shorter the wavelength it will respond to.

Pendry and his coauthors reasoned that by arranging many such artificial structures in a dense, periodic array—a two- or three-dimensional crystal—it should be possible to create metamaterials that respond to incoming electromagnetic radiation in a way that natural materials don't. In 2000, about a year later, a team led by David Smith and Sheldon Schultz at the University of California, San Diego, performed the first experiment that really demonstrated what metamaterials can do.

Smith and Schultz built 6.5-millimeter-wide split-ring resonators made of copper and spaced them out every 8 mm or so, placing a short length of wire in between each pair of resonators. When the researchers shone microwave radiation on the resulting structure, they showed that the material exhibited a mind-boggling property that doesn't exist in nature: a negative index of refraction.

A material with this property more or less puts light in reverse gear. The best way to see how this works is to consider two parameters that are used to describe light propagation—the velocity of electromagnetic energy propagation and the phase velocity. The first describes the overall flow of the light, and the second describes how the light waves—the individual peaks and troughs—move. In an ordinary material, electrons respond to incoming fields by jiggling in such a way that they create their own electromagnetic field. The resulting field—a combination of the incoming field and the material's response—will move in the same direction as the incoming

PREVIOUS PAGES, CLOCKWISE FROM TOP LEFT: KARLSRUHE INSTITUTE OF TECHNOLOGY; KARLSRUHE INSTITUTE OF TECHNOLOGY/ NATURE MATERIALS; KARLSRUHE INSTITUTE OF TECHNOLOGY; KARLSRUHE INSTITUTE OF TECHNOLOGY/APPLIED PHYSICS LETTERS

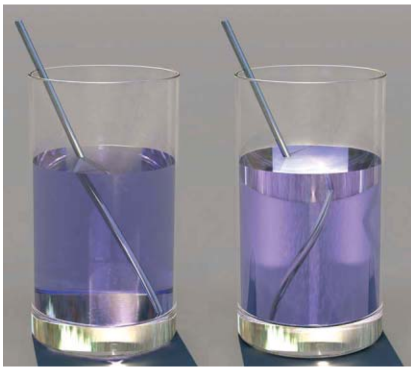
ILLUSTRATION BY Emily Cooper

radiation does, albeit with some lag and at a lower speed. As with the incoming field, both the energy and phase vectors are positive. But in a material with a negative index of refraction, energy and phase move in opposite directions. Although the energy of the light–and the light itself–still moves in the same direction as when it entered the material, the individual peaks and troughs actually move backward.

To picture how this would look in the real world, imagine a straw resting inside a half-filled glass. If the straw is standing in water, it will appear much as it does in air, with only a slight kink at the interface between the two materials. But if the glass contained a liquid with a negative refractive index, the straw would look bent, as if it were leaning in the opposite direction.

A material with a negative index of refraction could potentially be used to make superlenses capable of imaging objects at resolutions far below the wavelength of light that's shone on them. But the ability to control both components of light also offers other possibilities. Meta-atoms designed to act on both the electric and magnetic components of radiation equally, for example, could be used to create an "invisibility cloak" that works on the naked eye, steering light so that an object can be hidden from view.

We could also potentially make a metamaterial with electric and magnetic responses that destructively interfere, so that no radiation is reflected. If we could make that happen in a system that also absorbs light, we could create a perfectly black material that neither reflects nor transmits light, raising the possibility of more-sensitive detectors and more-efficient solar cells.



A NEGATIVE BENT: Artificial materials can be made to have a negative index of refraction, a light-bending property not seen in nature. The interface of air and water—two substances with positive indices—creates a small kink in the appearance of a straw [left]. If the liquid had a negative index of refraction, the straw would appear to bend in the opposite direction [right].

One other possible application is to filter out light with either a right- or left-handed circular polarization. The basic mechanism is similar to the way that sugar water, DNA, and other chiral materials–molecules with a physically distinct mirror image–rotate the polarization of a light wave. In those materials, the interaction is fairly weak, requiring light to travel for centimeters through the substance before it registers a strong change in polarization. A metamaterial, structured as an array of tiny helices, can accomplish its filtration task over much shorter distances. That could allow us to build compact devices that distinguish, for example, between pharmaceuticals and their mirror images, which may be identical in composition but have very different biological effects.

THAT'S ONLY A SMALL SAMPLING of what might be done with metamaterials. To get from blueprint to reality, we have to find a good way to make the underlying structures–the meta-atoms.

When the metamaterials field got its start a bit more than a decade ago, meta-atoms tended to be macroscopic: centimeter-size metallic split rings and wires printed on standard circuit boards. But these structures were so large they could act only on longer-wavelength radiation, in the microwave part of the spectrum. To make metamaterials that can act on visible light, which has a wavelength range of roughly 400 to 750 nanometers, the "atoms" must be on the order of 100 to 200 nanometers or smaller.

How do you make such small structures? You might think that a natural place to start is with the technology that's already been developed by the semiconductor industry. There are, after all, already powerful patterning tools, such as photolithography and electron-beam lithography, that are routinely used to fabricate submicrometer and nanoscale structures.

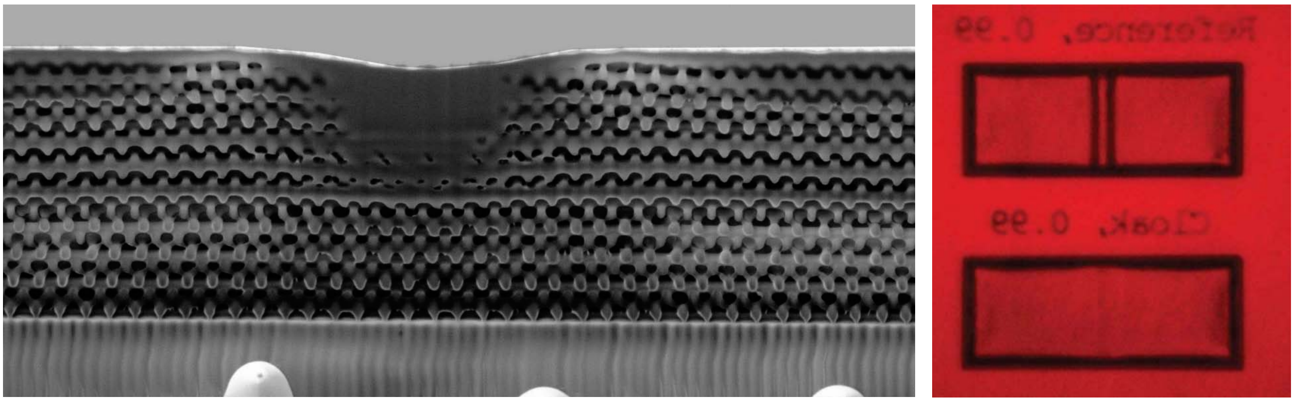
Indeed, groups such as those of Harald Giessen at the University of Stuttgart, in Germany; Vladimir Shalaev at Purdue University, in Indiana; Costas M. Soukoulis at Iowa State University; Xiang Zhang at the University of California, Berkeley; Nikolay Zheludev at the University of Southampton, in England; and ours at the Karlsruhe Institute of Technology (KIT), in Germany, have successfully used these techniques to create arrays of simple metamaterial structures, including split-ring resonators, that are small enough to act on visible or infrared light.

But these lithographic approaches begin to break down when you try to fabricate even seemingly simple 3-D objects, which is what you need for a metamaterial that can act on light regardless of direction. Lithography is designed to pattern 2-D features, so to construct an array of tiny helical coils, for example, you'd have to construct them layer by layer in hundreds of steps. It's a time-consuming process that requires careful alignment. Even research groups that are adept at the process might need an entire day to make a single layer.

Fortunately, there is a better way to make 3-D structures. The key is to use laser light, and some tricks developed over the last few years, to write in three-dimensional space. You could consider this type of optical lithography–direct laser writing–as a microscopic version of 3-D printing. Just as with rapid prototyping, or stereolithography, which was patented by Charles W. Hull in 1986, light is used to sketch out a shape. In this case, however, shapes are not made layer by layer. Instead they're all made in one go, out of a single volume of material. Solvent washes away what isn't exposed to light, much as Michelangelo might say an artist creates a sculpture: by chipping away excess stone.

AS IN OTHER LITHOGRAPHIC TECHNIQUES, direct laser writing uses a compound called resist–in this case, a photosensitive mixture called photoresist. To make metamaterials, we start with a thick layer of the stuff, which coats a glass slide or some other substrate and is mounted on a microscope. When we shine a laser through the microscope optics and onto the photoresist, the light breaks molecules apart and causes the exposed material to polymerize and harden. When we're done, we can wash away the unexposed material with solvent, and only the exposed material remains.

PHOTOS, THESE PAGES: LEFT, KARLSRUHE INSTITUTE OF TECHNOLOGY/ OPTICAL MATERIALS EXPRESS; RIGHT, KARLSRUHE INSTITUTE OF TECHNOLOGY/OPTICS EXPRESS



GONE IN 5 MICROMETERS: The polymer-based metamaterial above, made up of rods stacked in a woodpile-like arrangement, was the first to hide the presence of a 3-D object at visible wavelengths of light. This 5-micrometer-thick "carpet cloak" can make a 0.5-μm-high gold bump [parallel lines in center of top right image] appear as if it were a flat metal mirror for all polarizations of light and from nearly all angles of incidence.

Ordinarily, this approach would work well in only two dimensions. That's because even if we focused the laser deep into the resist, photons would be absorbed not only close to the focal region but also throughout the entire beam cone, below and above the focus. To make the curing process work in three dimensions, we alter the strategy slightly, pairing the "photoinitiator"–the part of the photoresist that absorbs photons–with a longer-wavelength laser. If the combination of the two is just right, we can create a system in which the photoinitiator must absorb two photons instead of one to become excited.

If two photons are needed, the absorption response isn't linear. Instead, it scales with the square of the light intensity; if we double it, we can get four times the response. That helps confine the effect of a laser: If a laser beam is tightly focused, the exposure will be sharply confined to a small volume around the center of the focus. Then, to draw an arbitrary 3-D shape, we need only move the focus around, by either moving the sample or the laser beam.

All by itself, however, this technique isn't quite enough to get us meta-atoms small enough to interact with light. The limitation is the Abbe diffraction barrier–a characteristic of microscope optics that limits the spatial resolution of a lens and thus how closely you can put two adjacent features or lines. For an 800-nm laser–which works well with common photoresists–and for high-end microscope lenses, you're limited to a lateral distance of about 300 nm because of Abbe.

For decades, this limitation appeared to be fundamental. But about five years ago, we proved there was a way past it. The idea got its start with physicist Stefan Hell, now at the Max Planck Institute for Biophysical Chemistry, in Göttingen, Germany. In the early 1990s, he proposed a way to break the diffraction barrier by using a second laser operating with a different frequency.

Through a process called stimulated emission depletion, this second laser can cause an excited molecule to spit out a photon and relax back to a lower energy state. That's useful for lithography, because, in effect, it gives us an eraser to go with our pen. The writing beam will have a hot spot in the center, and the erasing beam will have a different cross section: a specially shaped focus with zero intensity right where the writing laser is at its maximum [see illustration, "Writing Through Resist"]. When both beams are used, everything outside the very center of the writing beam can be de-excited, and the photoresist there will remain unexposed.

Hell's group was interested in using this technique to cause stained cells and other biological structures to fluoresce in as tiny a spot as possible, so they could be imaged at very high resolution under the microscope. (His team has since done this to great effect: In 2009, they showed they could resolve features under the microscope as small as 6 nm–just a few atoms across–using visible light, well under the Abbe diffraction barrier.)

But adapting the two-laser approach to curing photoresists wasn't easy. When our group at KIT started to look into the possibility in 2008, there were no photoresists that had been specifically developed to support the approach. One complication we encountered early on was that photoinitiators are designed to be efficient; after they're hit by photons, they react in almost no time at all, too fast for a second laser beam to de-excite the molecule and stop the polymerization reaction. It took about a year of research and some trial and error, but we eventually found a photoinitiator–a dye molecule that had been used only sparingly for lithography up until that point–that would do the job.

With that photoinitiator in hand, we found we could print structures with a lateral resolution–the distance between two adjacent features–of about 175 nm, about 40 percent finer than what can be achieved at the Abbe limit.

That's quite an improvement. But in principle, spatial resolutions of a few tens of nanometers (beyond that you're starting to reach the molecular scale) should be possible using 800-nm light. Pushing the resolution of this lithography down to such a scale will require more work. The problem is no longer optics; it's the photoresists that we use. For reasons that are still being explored–perhaps the diffusion of the photoresist molecules themselves–attempts to make smaller structures typically result in ill-defined features. If you try to make two features closer together than 175 nm, for example, you can end up curing areas that aren't supposed to be part of the final shape.

Still, the resolution is now fine enough to allow us to create artificial materials that can operate in the visible part of the spectrum. Many of them would have been impossible to make even five years ago. CONTINUED ON PAGE 53

LEFT: KARLSRUHE INSTITUTE OF TECHNOLOGY; RIGHT: KARLSRUHE INSTITUTE OF TECHNOLOGY/OPTICS LETTERS

Dream Jobs 2014

Happy engineers are all alike; each unhappy engineer is unhappy in his own way, Tolstoy might have said.

ACTUALLY, THE OPPOSITE IS CLOSER TO THE TRUTH. Those who are dissatisfied all tend to spend their days pining for positions that are more challenging or fulfilling. Those who enjoy their work derive satisfaction in many different ways. • The profiles we present in this year's Dream Jobs report aptly demonstrate that proposition. Contentment can come from working with professional athletes, investigating scientific mysteries, improving access to space, solving the problems of renewable energy, or just letting your imagination run. Reading about these exemplars may help you to zero in on your own uniquely rewarding career.

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I, Rocketeer

BRANDON PEARCE'S AVIONICS GUIDE SPACEX ROCKETS

AS A KID, HE PILED UP THE SCI-FI novels in the closet of his California bedroom–Isaac Asimov's Foundation series, David Brin's Uplift novels, Frank Herbert's Dune saga. He dreamed of going to space, not as an astronaut but as a citizen of a spacefaring society. But by the time Brandon Pearce reached high school in 1986, that dream was fading. When he looked at the missions going on at NASA, he just didn't see how they would lead to moon colonies, interplanetary travel, and deep-space adventures.

"The shuttle had started flying in the early '80s, but it wasn't doing very exciting things," says Pearce. "It wasn't opening new frontiers, it wasn't enabling new capabilities. The most exciting thing happening in space was Ronald Reagan's Star Wars [Strategic Defense Initiative], which was all about weapons. And I've never been interested in the weaponization of space. I was always interested in exploration."

NASA and its aerospace contractors didn't seem to be aiming to boldly go where no one had gone before–and they were the only game in town. So Pearce kept reading sci-fi, but he gave up on the idea of a job in aerospace. Instead he concentrated on getting an education and building a satisfying career as a computer engineer.

Then, in 2002, Internet millionaire Elon Musk founded the private company Space Exploration Technologies, known as SpaceX. Musk announced his intention to build cheap and reliable rockets to bring satellites and cargo into orbit, but he emphasized that such prosaic missions would be only the first step in his quest "to make life multiplanetary." Pearce was sold. Today, the computer engineer is the senior director of avionics hardware development for SpaceX, and he relishes the thought that every day on the job brings his sci-fi visions closer to reality.

The path that led Pearce to his dream job wasn't straight or obvious. He dropped out of college after one year to take a job as a technician with a consulting company in the San Francisco area. The work often brought him to semiconductor factories around Silicon Valley, and Pearce realized there were plenty of fascinating jobs for geeks like him–but he'd need to go back to school to get them.

BRANDON PEARCE

IEEE member

AGE 41

WHAT HE DOES Designs avionics for rockets and spacecraft.

FOR WHOM SpaceX

WHERE HE DOES IT Hawthorne, Calif.

FUN FACTOR Gets to send his work into orbit.

After earning both a bachelor's and a master's degree in computer engineering from the University of California, Santa Cruz, Pearce went to the Silicon Valley chipmaker Xilinx. During his first year of designing circuit boards, the tech bubble burst with a loud pop, but Xilinx remained a stable place to work. "I hunkered down," Pearce says. He kept designing boards there until 2006.

By then he had the expertise to move up the management ladder, but he was also enthralled by the brash space start-ups that were challenging existing ideas of who could build spacecraft and who could fly on them. Companies like Virgin Galactic and Xcor Aerospace were promising to take tourists on suborbital flights to experience weightlessness. SpaceX had even grander ambitions: It aimed to launch government satellites into orbit and win NASA contracts to resupply the International Space Station (ISS). Pearce followed the company closely and started rooting for its success. He remembers a vacation with his wife in Thailand in 2006 when he snuck away to an Internet café to watch the company's first rocket take off–it crashed into the ocean after less than a minute's flight.

That setback didn't dim Pearce's enthusiasm. So when a friend offered to bring along Pearce's résumé during a job interview with SpaceX, he accepted the offer without hesitation. Soon Pearce was heading to SpaceX headquarters in the Los Angeles area for interviews of his own. Then he was negotiating with his wife and his new boss about commuting to L.A. from Santa Cruz for a job in SpaceX's avionics department. That arrangement lasted for two years until his family relocated.

Moving to SpaceX felt risky, says Pearce: "I left a really secure job for a job I knew might not be there in a year's time." But he had no doubts about the decision. "When I started working at SpaceX, I joked with my wife that it might help me avoid a midlife crisis, because I wouldn't look back and wonder what I'd done with my life," he says. "I'm helping to execute Elon's mission, and the things I help design will hopefully end up taking people to Mars. This is what I grew up on as a kid."

The SpaceX factory and headquarters are located in a massive hangar near the Los Angeles airport. While the company now has more than 3000 employees, it has held on to whimsical start-up features like a free frozen yogurt station. Right next to the fro-yo sits the first Dragon space capsule, blackened and scarred, which in 2010 successfully orbited Earth before splashing down in

RETOUCHING: G-TOU

PHOTOGRAPH BY Gregg Segal

the Pacific. Since then, unmanned Dragon capsules have docked with the ISS, bringing cargo, and SpaceX is working toward the day when its spacecraft will also ferry crew up and down.

Pearce's department is responsible for all the electronics in the SpaceX rockets and capsules, which include sensors, communications equipment, guidance and navigation systems, and engine-control mechanisms. Each component must be robust enough to stand up to high temperatures, intense vibration, and radiation. And the systems have to do their jobs even when isolated malfunctions occur, so that one failure doesn't bring down the entire mission.

Pearce currently oversees avionics R&D, leading a group of about 60 people. On his to-do list is the development of sensors for SpaceX's newest project, a reusable rocket known as Grasshopper, which has already completed several vertical-takeoff, vertical-landing test flights. Reusable rockets are key to Musk's vision of bringing life to other planets, because they're far more economical. He has argued that fully reusable space vehicles could reduce the cost of reaching orbit by a factor of 100.

So what's it like to work for a daredevil entrepreneur who is trying to reinvent the aerospace industry? According to Pearce, the best and the worst things about working for Musk are actually the same. "He doesn't feel the need to make reasonable requests," Pearce says. "The whole idea of SpaceX is not reasonable. The idea that a dot-com millionaire could take [US] $100 million and start a rocket company that within 13 years would be taking supplies to the International Space Station, that's on track to take crew to the International Space Station–that's not reasonable."

Having a boss who dreams big makes work extremely exciting and challenging, says Pearce. "But at the same time, you can never say to Elon, 'You're asking us to do that, but that's not reasonable.' You have to either figure out how to do it or get as close as you can," he says. Reusable rockets? They're working on it. A manned expedition to Mars? They'll tackle that next. –ELIZA STRICKLAND

The Willy Wonka of Electronics

SONY'S JUN REKIMOTO DREAMS UP GADGETS FOR THE FAR FUTURE

JUN REKIMOTO stands in the corner of his office, frowning at a small white refrigerator. He's not worrying about his diet–in fact, there's no food inside. Rather, he's showing off a new method of interactivity with the world of appliances, as a red frowny face lights up on the door of the fridge. "You see, it won't open until I smile," he says, pulling on the door to demonstrate that it's locked shut. Then the pensive researcher's face is transformed by a beaming grin. The fridge responds with a smiley face of its own, in bright green, and the door swings open.

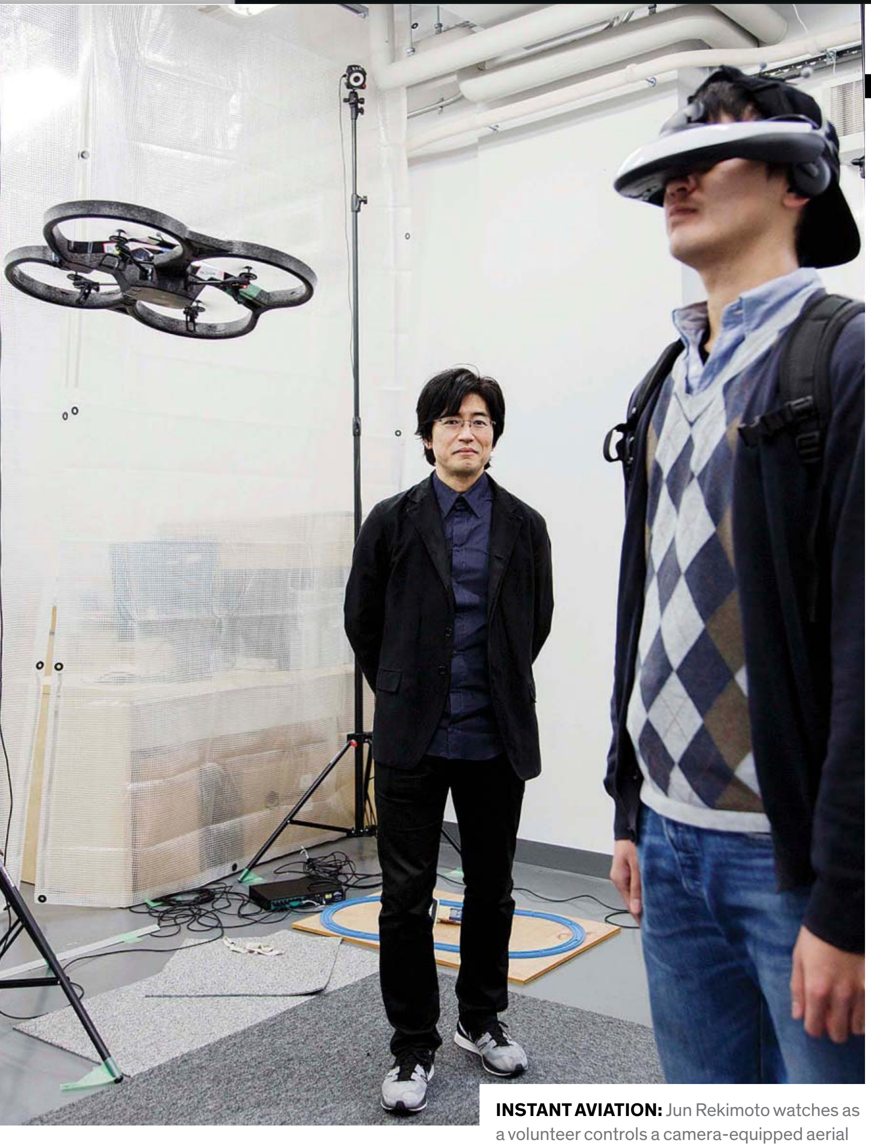
This emotionally engaged fridge is one of Rekimoto's many inventions for Sony, but don't expect to see expressive appliances in stores anytime soon. Sony, as one of the most successful consumer-electronics companies on the planet, has plenty of research-and-development labs devoted to improving its televisions, computers, cameras, and so forth. But Rekimoto works at Sony Computer Science Laboratories (CSL), in Tokyo, an exclusive scientific sanctum where researchers are encouraged to pursue their wackiest ideas and push the limits of technology. Rekimoto needn't concern himself with whether or not his creations will turn into products in the near term, because Sony wants him to invent gadgets for a future that consumers haven't even imagined yet.

Rekimoto trained his own imagination early. He became fascinated by computers when he was growing up in Tokyo, and in 1971, at the tender age of 10, he went to a bookstore and purchased a textbook about programming. There was only one barrier to his learning: The personal computer didn't exist yet, and a 10-year-old wasn't likely to gain access to a university's mainframe. So he wrote out his programs in a notebook and imagined the results. "I wrote them down like a mantra," he says, "like magic words."

Nowadays he has plenty of computers at his disposal. Rekimoto is sitting in his office at the University of Tokyo–he added a professorship in information science to his job at Sony a few years ago. The table in front of him is littered with miscellaneous electronic parts and tiny screwdrivers, finished projects hang from the walls and sit stacked on shelves, and a team of graduate students work in the lab across the hall.

Although Rekimoto's projects are wide-ranging, most focus on the interfaces between humans and technology. The topic first fascinated him during his undergraduate studies at the Tokyo Institute of Technology in the early 1980s. There, he came across an article by Alan Kay, a legendary computer scientist from Xerox's Palo Alto Research Center, that discussed graphical computer interfaces. Rekimoto loved the idea, and decided to devote his career to crafting new ways for people to interact with machines.

After earning both bachelor's and master's degrees in information science, Rekimoto took a job in the R&D department of NEC Corp., a computer and communications giant, where he worked on interfaces for Unix. Had he followed the traditional Japanese career path, Rekimoto would have stayed at NEC until retirement. But in 1993, when he



INSTANT AVIATION: Jun Rekimoto watches as a volunteer controls a camera-equipped aerial vehicle with intuitive motions of his head.

came back from a stint as a visiting scientist at the University of Alberta, in Canada, he found himself in Japan's post-bubble economy. NEC and many of the other big technology companies no longer had big budgets for R&D.

In Canada, he had played around with virtual-reality systems but had been disappointed with their unrealistic graphics. A better approach, he thought, would be to layer information over the real world–a strategy now called augmented reality. But he knew such research would be expensive and wouldn't pay off in the short term, making it unlikely that NEC would support it.

So when he received an offer to join Sony CSL, he jumped

JUN REKIMOTO

IEEE member

AGE 52

WHAT HE DOES
Invents new ways for humans and machines to interact.

FOR WHOM
Sony Computer Science Laboratories

WHERE HE DOES IT
Tokyo

FUN FACTORS
Has the freedom to build whatever he can dream up.

at the chance. He remembers that CSL founder Mario Tokoro warned him that the job wouldn't be anything like working for one of Japan's technology giants. "Mario told me, 'You'll have freedom, but freedom is very hard, freedom means responsibility–there are no excuses,'" Rekimoto recalls. He'd have to dream up his own assignments and push himself to complete them.

One of his earliest projects, NaviCam, used a handheld computer with a video camera, something remarkably similar to today's smartphones. With this device, a user could scan bar codes and the correlating information would appear on the screen, overlaid on the user's view of his or her surroundings. For example, if a user scanned a code on the front door of the CSL office, the display showed the paths to various meeting rooms and researchers' offices as arrows on the floor.

Some of his experiments did go on to inform Sony's commercial products, like his work with near-field communication, or NFC. Nearly ten years later Sony introduced electronic gear, including camera lenses and speakers, that communicate with a smartphone via Rekimoto's NFC system.

Rekimoto thinks that a good user interface enhances human capacities, a view he first heard expressed by Douglas Engelbart, the inventor of the computer mouse. "He said that the mouse was just a tiny piece of a much larger project aimed at augmenting the human intellect," Rekimoto remembers. "So my work has become more about human augmentation."

One recent project, Flying Head, involves a headset that the user wears to both see through the eyes of and control a small unmanned aerial vehicle, or UAV. "You wear the headset and you feel that you can fly–you can *be* a helicopter," he says. Rekimoto imagines such a system being useful for a nonpilot specialist who needs to access a dangerous area, such as the ruins of Japan's Fukushima Daiichi nuclear power plant. A UAV could fly above the radioactive rubble, where wheeled robots would have difficulty progressing, and the specialist guiding it remotely could examine the damage from a safe distance.

Even the grin-operated fridge fits into Rekimoto's vision. That project, he explains, also aims for human augmentation: By encouraging its users to smile more often, the fridge can improve their mental well-being. "If it is our destiny to merge with machines, we should think about what parts of humans can be augmented by that merger," he says. "Technology shouldn't just improve our intellectual abilities–technology should make you happy." Rekimoto and his fridge exchange another smile. –ELIZA STRICKLAND

PHOTOGRAPH BY Jeremie Souteyrat

Solar-Energy Innovator

OTHERLAB'S LEILA MADRONE IS BRINGING ROBOTICS TO RENEWABLE ENERGY

LEILA MADRONE'S EARLIEST ASPIRATION was to work for the National Aeronautics and Space Administration. "When I was seven, I wore a black NASA jacket every single day," says Madrone. A quarter century later, after earning two degrees and designing robots of all shapes and sizes at MIT, she attained that goal, landing a job at NASA's Ames Research Center in Mountain View, Calif.

Her work there—on the GigaPan imaging project, a spin-off of the Mars rover missions—was enjoyable, but deep down she didn't find it satisfying. Madrone wanted her toils to have greater social impact. So after careful thought, she decided to apply her background in robotics to solving some of the problems of renewable energy. Her new ambition is "to make solar energy actually work." She's now pursuing that objective at Otherlab in San Francisco, where she's doing R&D that could one day make solar energy competitive with coal, even in the developing world.

Madrone didn't expect to make significant inroads right away. Her first step was identifying a solar company that could use her skills in robotics so that she could learn more about the solar industry. At the time, GreenVolts, then based in Fremont, Calif., seemed to fill the bill. It was developing systems to concentrate sunlight on high-efficiency photovoltaic cells, so it needed equipment capable of tracking the sun precisely. "This is great," Madrone remembers thinking. "This is robots, but with a solar device on the end of it."

After working at GreenVolts for a couple of years, Madrone began to have misgivings. "I started to realize how expensive it was to have a precision robot, a big metal precision robot, move around something to collect photons," she says. "I didn't see this being an energy source that's going to change the world."

She was discouraged, too, by the economy, which at the time—2009—was taking a beating, causing GreenVolts to lay off most of her engineering colleagues. She decided to leave as well and travel overseas. As she had just gotten married, it would be an extended honeymoon but with a professional component. "I wanted to see how people actually interact with energy in the world," says Madrone.

Her conclusion about solar energy after five months touring Europe, Asia, the Middle East, and Mexico? "It really had to be cheap," she says. "It couldn't just be cheap for someone in San Francisco or the U.S. It had to be cheap for people everywhere."

Returning to California, she wrote in some desperation to Saul Griffith, a friend from her MIT days. Griffith had recently founded Otherlab, which Madrone describes as being "like a cross between a start-up company and an academic lab." By happy coincidence, he, too, had been toying with various solar-energy ideas, and he invited her to improve on his preliminary work.

PHOTOGRAPH BY Gabriela Hasbun

Their premise was that equipment to harness the sun's rays could be made very cheaply. If the manufacturing costs could be kept low, they reasoned, the price would be proportional to the mass and cost per kilogram of the constituent materials. So the key would be to use, as much as possible, stuff that is both lightweight and inexpensive. What stuff? The answer struck them as obvious. Solar energy's future, to borrow a line from *The Graduate*, could be summed up in one word: plastics.

Madrone and Griffith eventually got funding from the Advanced Research Projects Agency–Energy (ARPA-E) to work on better ways to steer the mirrors of a solar-thermal-energy plant. These mirrors focus sunlight throughout the day on towers containing steam-driven generators. Mechanisms that accomplish that task—called heliostats—have been around for decades, but they are not cheap.

Madrone and Griffith realized that they could cut down on the heft required of the heliostats by using a huge number of small mirrors to replace what would normally be a smaller number of big ones. Small mirrors hug the ground and thus carry smaller wind loads. And small, light-duty heliostats could be built from plastic, following an approach that's similar to the way certain flowering plants track the sun's daily movements. "Originally, we were origami inspired, and now we're bio inspired," says Madrone.

Her latest prototype aims a mirror by varying the pressures within pneumatically inflated plastic chambers, which can be mass-produced with the same tooling used to make plastic bottles. "If we keep using heliostats that have been around for half a century, there's no way the price is going to go down," says Madrone. "If we don't start taking advantage of new technologies, we're just going to lose the solar game."

A typical workday for Madrone as she tries to win that game might entail consulting with outside experts, modeling electronics in SPICE (Simulation Program with Integrated Circuit Emphasis), writing reports for ARPA-E, laying out a printed-circuit board, preparing a patent application, or any combination of such tasks. And she gets to do those things in historic surroundings: a building in San Francisco's Mission District that once housed a pipe-organ factory. With antique organ pipes adorning the walls and aging hardwood everywhere, the building retains a turn-of-the-20th-century air. Other projects being pursued there include inflatable robots, form-fitting fuel tanks for natural-gas cars, and an electric cargo tricycle that lets the rider lean into turns.

The engineers at Otherlab have tried to preserve their building's Arts and Crafts aesthetic, foregoing steel desks for oak ones and using old library card catalogs in place of the usual plastic parts bins. Casual visitors could easily imagine they've wandered into the mad inventor's lair from a steampunk novel.

Even more pleasant than the ambiance, Madrone explains, is the nature of the people she's laboring alongside. "There's this cultural bias that if you want a hard-core engineering company, everyone's got to be intense and aggressive and arrogant and all of that," she says. "Here people are confident but not arrogant, and thoughtful instead of aggressive."

Best of all for her, though, is knowing that her designs could have a real impact. "I think a dream job is getting to work on something that is really relevant that you're passionate about every day," she says. "For me, that is what the dream is."

– DAVID SCHNEIDER

LEILA MADRONE

IEEE Member

AGE 37

WHAT SHE DOES Investigates ways to produce solar energy cheaply.

FOR WHOM Otherlab

WHERE SHE DOES IT San Francisco

FUN FACTORS Her office appears in the National Register of Historic Places.

Deep-Earth Detective

SIGNALS SPECIALIST KARIN SIGLOCH PROBES THE PLANET'S DARKEST SECRETS

SIXTY-FIVE MILLION YEARS AGO, IN THE WANING days of the dinosaurs, when India was still floating alone near Madagascar, an upwelling of hot rock from deep in the Earth's mantle called a plume broke through the continent, depositing a 2-kilometer-thick blanket of volcanic material that can still be seen today. Then India migrated northeastward, eventually slamming into Eurasia. But the plume stayed put. And as the Indian and African plates passed over it, it spawned a chain of volcanic islands that now decorate the floor of the Indian Ocean. Today, that plume sits under Réunion, a French island located east of Madagascar.

That's the hypothesis anyway. And Karin Sigloch is determined to test whether it's true. She's a geophysicist at the University of Oxford, in England, where she uses vibrations from earthquakes to image the planet's interior. By observing the waves' arrival at recording stations called seismometers, she is able to model, using supercomputers, how the waves slow and scatter as they travel through the Earth, revealing hidden subterranean structures.

Her career may seem an unusual choice for an engineering major. But Sigloch believes she couldn't have found a job more thrilling. After all, she is illuminating the very rock beneath our feet—a place just as dynamic and yet less studied than outer space.

SCIENCE

Sigloch, who grew up in Germany, wasn't always into earth science. As a child, she was fascinated with music, particularly the nature of sound. In seventh grade, her favorite book was a beautifully illustrated tome called *The Science of Musical Sound*, written by John R. Pierce, who helped pioneer communications satellites at Bell Telephone Laboratories. In high school, Sigloch decided to pursue engineering, imagining she might one day design acoustics for concert halls.

She entered a joint-degree program at the University of Karlsruhe, in Germany, and the Grenoble Institute of Technology, in France, earning the equivalent of both bachelor's and master's degrees in electrical and computer engineering in only five years. During her final year, in 2001, she had the option to finish her studies outside Europe, and so, inspired partly by Pierce's book, she went to Bell Labs in Murray Hill, N.J. The decision turned out to be a pivotal one.

Although AT&T's spin-off company Lucent Technologies now owned the labs, the place retained much of its freewheeling, collegial culture. "It was incredibly creative, very heady, and very, very fun," Sigloch remembers. Researchers regularly used their lunch breaks to solve one another's problems and debate wild ideas. "After that experience, I thought the coolest thing would be to be a researcher," Sigloch says. But what kind?

During the 18 months she worked at Bell Labs, Sigloch experimented with new wireless-transmission schemes. Although the work satisfied her, she didn't think she wanted to spend her career studying cellphones. "So I asked the lunch table what I should do." Her colleagues pushed her to consider subjects beyond pure engineering. "They said, 'You have to find a beautiful field for yourself, something that appeals to you on a gut level,' " she remembers.

She took the advice to heart, considering doctoral programs in space weather and neuroscience before zeroing in on a geoscience lab at Princeton. There, she could use her knowledge of waveforms to peer into the deepest recesses of the Earth–places people had theorized about but never seen. "I just thought that would be a great privilege," she says.

At Princeton, Sigloch perfected the computational techniques she would need to turn seismic signals into 3-D pictures of the Earth's interior. And with help from her thesis advisor, Guust Nolet, she began developing new algorithms that could produce high-resolution images. To test them, the scientists needed data.

The set they chose came from a grid of 400 movable seismometers called the USArray, which was slowly making its way across the contiguous United States. Beginning in California in 2004, seismologists buried the basketball-size instruments in 2-meter-deep holes, where they remained for two years before being dug up and transplanted further east, ending in Maine last October. When Sigloch got hold of the data, in 2006, the array had scanned only the westernmost states. But that was enough to take a snapshot of what lay beneath.

The picture she and her colleagues produced was game-changing. For decades, geologists believed that when North America and Africa began drifting apart some 200 million years ago, the vast Pacific Ocean sat atop an enormous sheet of rock called the Farallon Plate. They assumed that as North America pushed westward, the Farallon subducted under it, sinking into the hot mantle below as mountain chains rose above. But Sigloch's study showed that whatever lay beneath North America didn't descend as one continuous slab. Instead, it submerged in fragmented chunks, like a series of lumpy walls.

For years, she struggled to explain what she was seeing. But eventually, she pieced together a story. The ancient Pacific, she realized, wasn't made up of one plate but at least three. And where these plates collided, molten rock welled up, forming island chains such as in Indonesia. Each plate then subducted separately, creating the mysterious walls that Sigloch had discovered under

KARIN SIGLOCH

IEEE Member

AGE 38

WHAT SHE DOES Uses seismic data to image the Earth's interior.

FOR WHOM University of Oxford

WHERE SHE DOES IT In Oxford, England, and on research ships in the Indian Ocean

FUN FACTORS Gets to visit tropical islands that are off-limits to casual tourists.

PHOTOGRAPH BY Antoine Doyen

North America. Meanwhile, as the continent moved west, it plowed into the island chains, erecting the mountain ranges that now stretch from Alaska to Mexico.

After receiving her Ph.D. from Princeton in 2008, Sigloch took a job as an assistant professor at Ludwig-Maximilians-Universität München, in Germany, where she worked until moving to Oxford last October. One day, she got an e-mail from a French colleague, Guilhem Barruol. He said he was moving to Réunion and wanted to investigate the island's volcanic source. Sigloch told him that the German government had recently bought 80 ocean-bottom seismometers for scientific research, and she suggested they distribute them near the island in hopes of imaging the hypothesized plume below.

By 2011, they had raised enough funds from the French and German governments for 57 ocean-bottom stations and 37 new land stations on Réunion and nearby islands. That year, they set up the land stations, sailing to pristine coral atolls, some of them uninhabited nature preserves where they watched sea turtles hatch and hordes of giant hermit crabs snatch liver pâté from their sandwiches.

The next year, with help from a small crew of colleagues and students, they deployed the ocean-bottom stations. The cruise lasted five weeks. Each day, the researchers assembled the instruments in a makeshift workshop inside the ship's helicopter hangar and hauled one or two overboard using the ship's crane. At night, they ate cheese and sipped wine and rum punch. The team returned to Réunion to retrieve the ocean-bottom sensors in 2013, but it will take years to process all of the data.

Sigloch concedes that her work can sometimes feel tedious. And she probably could have made more money had she stuck with the cellphone industry or used her training in geophysics to get a job with an oil company. "But that wouldn't bring the same intellectual excitement," she says. "You can only discover something once. If we find a plume under La Réunion, then for this place on Earth, we will have settled the question of its existence once and for all." —ARIEL BLEICHER

Baseball's Most Valuable Coder

SPORTVISION'S MARK PERRY TRACKS BASEBALL PLAYERS' EVERY MOVE

TALL AND LANKY, Mark Perry (no relation to this author) looks like the professional baseball pitcher he once dreamed he'd become. But it's his coding, not his fastball, that got him into the major leagues.

Perry works for Sportvision, in Mountain View, Calif., the company that creates and operates tracking and graphics systems for sporting events. If you've ever watched American football on television, you've probably seen one of the company's early innovations—a virtual first-down line "painted" across the screen in bright yellow.

Perry is Sportvision's lead engineer for baseball, developing software to analyze pitches, hits, and soon, the movements of the players themselves. It's the perfect job for a baseball fanatic turned engineer.

Perry didn't step right off the pitcher's mound into this line of work—but almost. Although he was good at math and science in high school, his main interest was baseball, which he intended to make his career. But during his senior year, a lower-back injury knocked him out of the starting rotation and into the bullpen, forcing him to consider other possibilities.

When he entered California Polytechnic State University, in San Luis Obispo, in 2001, he planned to keep playing while simultaneously studying engineering. But then his classes got tough. It was decision time. "I love baseball," Perry says. "I will never stop loving the game. But I realized I couldn't do both halfway, so I chose the safer route."

During his junior year, that safer route included a wrong turn. Perry took a co-op engineering job with Cisco Systems, doing hardware testing. "It just wasn't for me," he says.

Seeking more of a challenge, he started looking for an internship writing software. That's when his mother stepped in. Earlier she'd had a chance meeting with Rob Amyx, Sportsvision's senior manager of special projects. Although Amyx hadn't described his work in great detail, Perry's mother got the sense that he worked for a company that sometimes sent engineers to sporting events. She thought that sounded like a good fit for her baseball-crazy engineer son and insisted that he send Amyx his résumé.

Amyx passed the résumé on to Sportvision's engineering team, and Perry landed a three-month summer internship, where he found himself assigned to a golf project. Perry doesn't play golf, but he knew that Sportvision was still the right place for him. For one thing, he says, it was great to be surrounded by people who cared about sports; in addition to golf and football, Sportvision has products for motor sports, baseball, and sailing. Also, working at Sportvision felt a lot like being a

professional athlete, he says, because he traveled to sporting events as part of the event, not as a spectator.

That summer Perry built an interface between a database containing golfer statistics and a system that created display graphics as part of a TV broadcast. It wasn't a huge project, but it was all his.

As college graduation approached, Perry applied for jobs at a number of large Silicon Valley companies, but without much enthusiasm. He really wanted to work for Sportvision. So he kept e-mailing the company's chief technology officer, begging for a job. It worked: A week before graduation, he got an offer—a position developing software for the Indy Racing League, a series of races that culminates in the Indy 500. He started in January 2006.

As part of the new job, Perry traveled around the country to Indy events. It was a blast. "I was newly 22, just graduated, and I got to see the nation and watch sports," he says. For about eight months out of each year, he was on the road almost constantly. The graphics and tracking system for the Indy races was new, so bugs needed to be fixed and features added on the fly. Sometimes he stayed up at the racetrack all night coding and released the updated software in the morning, without any reasonable time for testing. "It's not the best way to code," Perry admits. "But it's a stress that I was used to in sports—the pressure of delivering something when it's needed. I thrive in those kinds of situations." The other third of the year he worked in Sportvision's Mountain View offices, doing more extensive software development in preparation for the next racing season.

This was in many ways his dream job—with one catch: Auto racing wasn't baseball. But in 2009 Perry became managing engineer of the team behind Pitchf/x, software for tracking baseball pitches and displaying their trajectories on TV.

Major-league ballparks were already using Pitchf/x. Perry's assignment was to help roll it out into minor-league ballparks. While major-league Pitchf/x was then primarily used just to enhance television broadcasts, the minor-league system was going to go further—it would collect and distribute data and video to teams in real time. And more than just the path of the pitch would be available. "We always had the equation of motion that defined the pitch," Perry says. "We use that to draw the trail of the ball and show where it crosses home plate."

The equation includes nine parameters, including initial position, velocity, and acceleration. Coaches and scouts find some of these parameters useful because they can reveal minute changes in a pitcher's delivery.

Perry's group has also developed a system called Hitf/x, to track aspects of hitting, including the contact point and the angle the ball takes as it comes off the bat. As with its pitching data, Sportvision has found that this information is valuable to coaches and scouts. More recently, Perry started working on software for tracking the position, angle, and velocity of different parts of a player's body.

Perry's not at all sour about giving up his youthful aspiration of becoming a pitcher. "I'm okay with not playing pro sports, because I am really part of pro sports," he says. "I see the games from the sidelines, next to the athletes. And they treat you like you're just like them. You're not there to harass them; you're working together."

The only downside of being a sports professional instead of an ordinary fan, Perry explains, is that now he can't ask for autographs. —TEKLA S. PERRY

MARK PERRY

IEEE Member

AGE 30

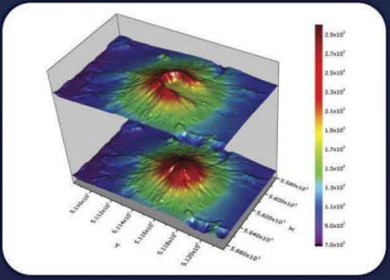
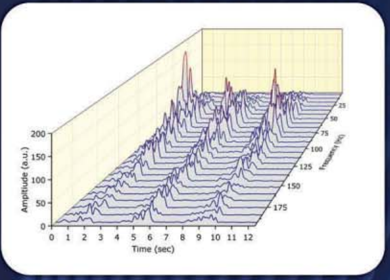
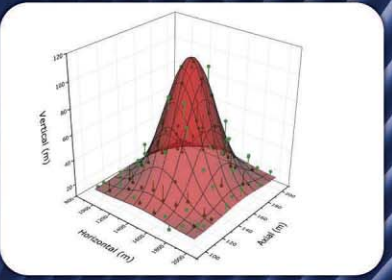
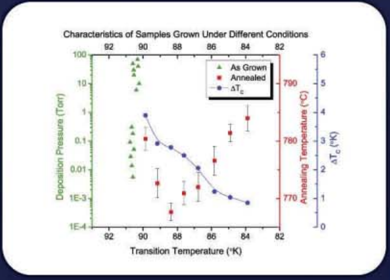
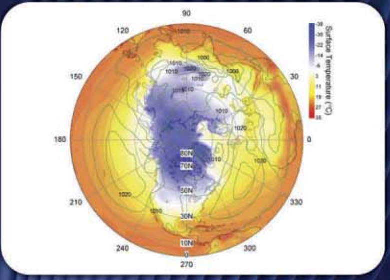
WHAT HE DOES Creates tracking, data-collection, and television-graphics systems for professional baseball stadiums.

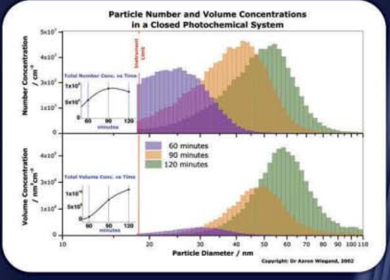
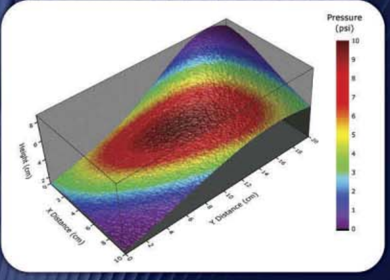
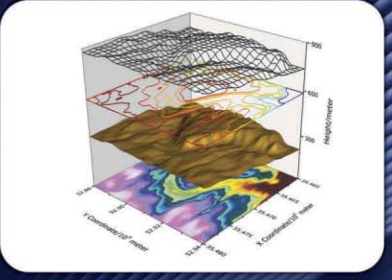
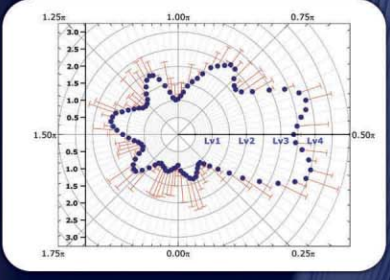
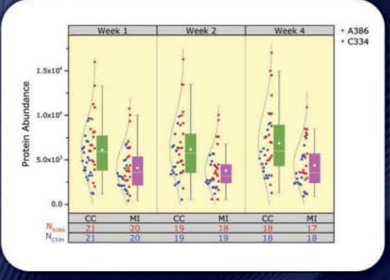
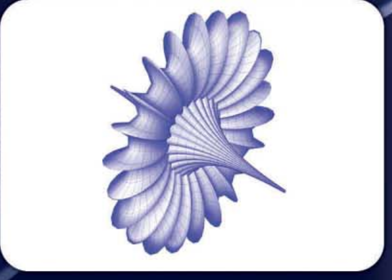
FOR WHOM Sportvision

WHERE HE DOES IT In Mountain View, Calif., and in major- and minor-league ballparks around the world

FUN FACTORS Gets access to the press box, clubhouse, and field during baseball games and gets to throw pitches in the parking lot as part of software testing.

PHOTOGRAPH BY Gabriela Hasbun

A DAY IN THE LIFE OF DIGI-KEY

With a million products in its catalog, the global electronics distributor caters to corporate engineers and hobbyists alike

PHOTOGRAPHY BY **GREGG SEGAL**
TEXT BY **JEAN KUMAGAI**

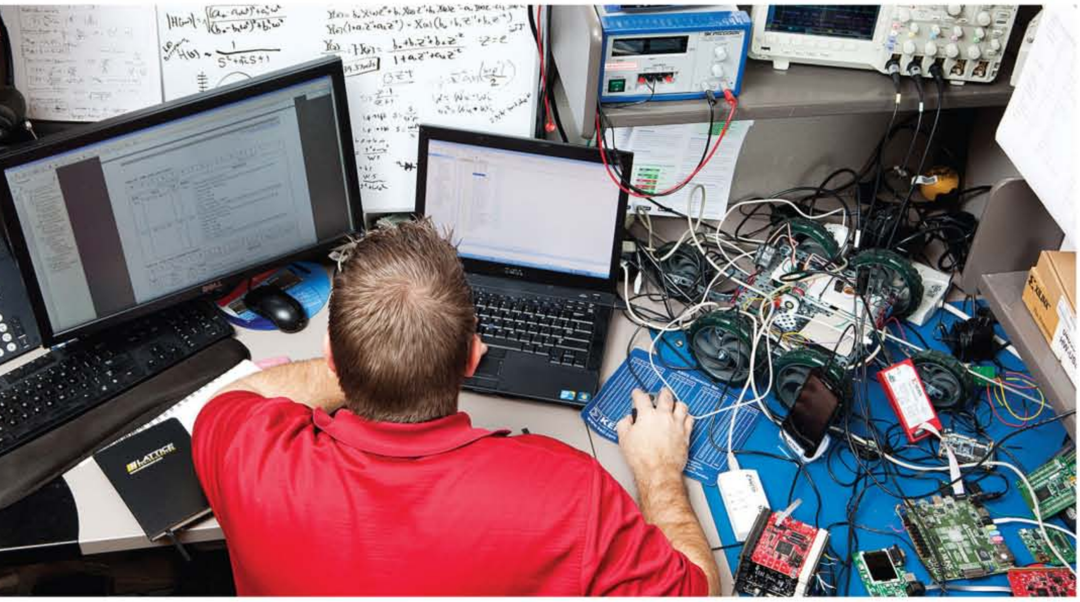
IN THE 42 YEARS SINCE ITS FOUNDING, Digi-Key Corp. has grown–and grown–into one of the world's largest electronic-component distributors. Its online catalog features nearly a million parts and products. Last year it sold US $1.6 billion worth of merchandise to more than half a million customers in 170 countries. And the vast majority of Digi-Key's offerings are kept in stock, available for immediate shipping, in a single place: the company's 74 000-square-meter warehouse. ● That enormous warehouse sits on the southwestern edge of the tiny town of Thief River Falls, Minn. The nearest city is Grand Forks, N.D., hardly a metropolis. The warehouse operates around the clock, 365 days a year, with the result that any order placed by 8 p.m. local time gets shipped out the same day. ● Digi-Key, like its archrival Mouser Electronics, caters to both corporate clients and hobbyists. The company will gladly sell you a Xilinx Virtex-7 field-programmable gate array for $39 452.40, but it will also sell you a single 10-cent through-hole resistor. ● When you call Digi-Key's toll-free number, an actual person answers, usually within 5 seconds. From there, you'll be guided expertly, even if you have no idea what you need, even if all you're getting is that 10-cent resistor, even if you speak Chinese, Hindi, or Portuguese. In an age of impersonal e-commerce, of voice mail that never gets returned, of languishing on hold, the experience of being a Digi-Key customer can seem almost surreal. ➜

TO GO

To move packages efficiently around Digi-Key's huge warehouse, Danielle Wollin relies on a specialized scooter cart. A staff of 2600 keeps the facility operating 24 hours a day, 365 days a year.

FAR AWAY

"If you were to start with a blank sheet of paper and say, Where would be the logical place to locate an electronic distributor like Digi-Key, this would probably not have been the place," admits company president Mark Larson. The rural northwestern corner of Minnesota, where Digi-Key is based, is far from any industrial or transportation hub, and the sparse population makes hiring a challenge. Somehow, though, the company makes it work: Special agreements with FedEx, DHL, and UPS guarantee daily air-freight service, and buses bring employees in from an hour or more away.



HELPING HAND

[Far left] As Digi-Key's in-house specialist on FPGAs and ARM cortex microcontrollers, application engineer Tony Storey evaluates the latest products so that he can guide customers through their design options. He and his colleagues also contribute tutorials to the website EEwiki.net. "There's too many technologies for any one person to know about, so we help people find the best fit for their project," Storey says. His customers include "everyone from people living in their mom's basement building a perpetual motion machine to design engineers in large companies," he says. "If we have time, we're happy to help."

BEYOND BUBBLE WRAP

[Left] Customers specify how each part of each order gets packaged for shipping. If, say, a given set of parts is destined for placement on a printed circuit board, you can have the parts shipped on a "cut-tape reel." A Digi-Key packer will wind the parts onto a standard-size reel, each part in its own enclosure. Once you receive it, you can pop the reel onto a pick machine, which will place the part onto your PC board. Of course, if you just want the parts shipped in a plastic bag, they'll do that too.

RAPID FIRE

[Above] Within minutes of receiving an order, human "pickers" locate the desired parts and send them along via conveyor belt for packing. When the odd part can't be found, a dedicated team scours the shelves, tracking down such exceptions. Digi-Key guarantees that any order placed by 8 p.m. U.S. central time will be shipped out the same day. A recent expansion, including 38 new pick stations, 26 new pack stations, and 2600 additional meters of conveyer belt, means the facility can now process 24 000 orders a day, or one every 3.6 seconds.

HOMEGROWN

[Above] Thief River Falls native Mark Larson [shown] joined Digi-Key several years after it was founded by Ron Stordahl, another local and a childhood friend. At the start, the company offered just one product: a solid-state Morse-code keyer for ham radio operators. Anticipating high demand for his "digi-keyer," Stordahl optimistically bought tens of thousands of transistors and other components for his design. But orders were slim, so he began selling the components themselves by mail order. "That proved to be a much better business," Larson says. These days, the company stocks nearly a million products, up 50 percent in just the last two years.

BESPOKE CABLE

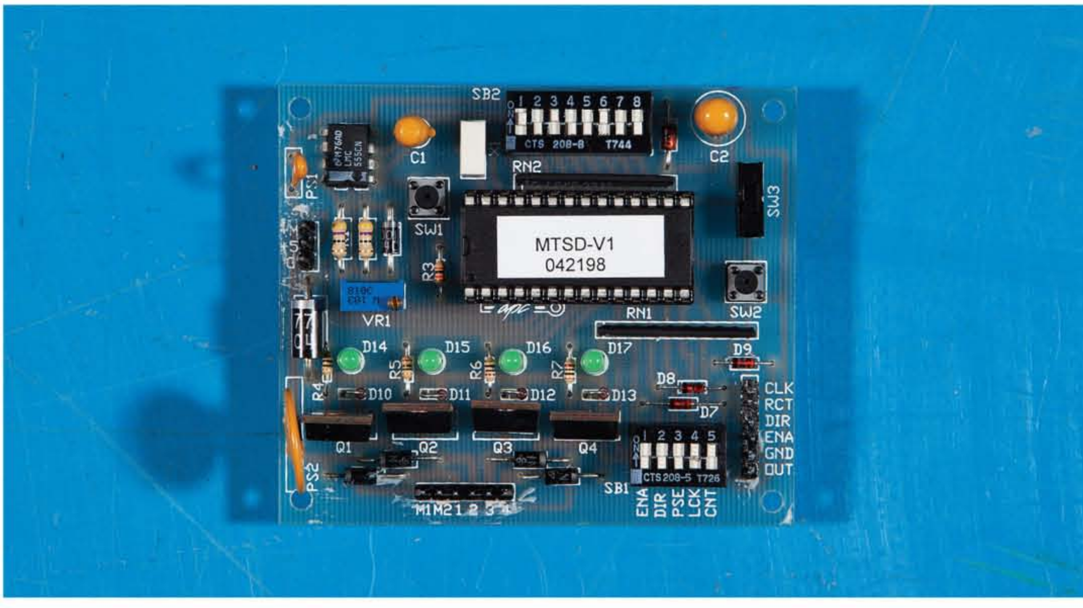
[Right] Flex cables, like cut-tape reels, can be custom ordered; you can specify the length, the number of pins or other connectors, and the label, among other things.

FINAL FRONTIER

[Far right] A stepper-motor control board designed by Digi-Key engineer Shawn Rhen was added to the Digi-Key catalog in the 1990s. One day, Rhen got a call from someone who said he was with NASA and wanted to use the board on the space shuttle. "I thought it was a joke," he recalls. It wasn't: Mission STS-95, which launched on 29 October 1998, took Rhen's board into orbit as part of a microvibration detection experiment. The experiment went off without a hitch, and the principal investigator later returned the board to Rhen.

REEL TO REEL

Completed cut-tape reels get a final check and a routing label before being boxed up for shipping.



AWAY WE GO

Once an order has been picked and packed, the last stop before it leaves the Digi-Key facility is the shipping bay. UPS and FedEx both have employees on-site to scan in packages and load them directly into air-freight containers or onto delivery trucks. From the Thief River Falls airport, FedEx flies directly to its global "superhub" in Memphis, Tenn., while UPS flies to its main hub in Louisville, Ky. Return flights the next morning will bring in new parts, mostly from Asia, to restock the Digi-Key warehouse. Domestic deliveries can be in customers' hands the same day, while those bound for Western Europe or Japan take about 48 hours on average; customers in China can expect a turnaround of about 60 hours.

GROWTH SPURT

[Above] Although Digi-Key holds true to its Minnesota roots, it has recently opened sales offices in China, Germany, Israel, Italy, Poland, Sweden, and the United Kingdom.

TIME OUT

[Left] A worker takes a breather in one of the many break rooms that dot the warehouse, while a colleague peruses the shelves just beyond.

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Matter Made to Order

CONTINUED FROM PAGE 34

RETURNING TO OUR FAVORITE EXAMPLE, the invisibility cloak: When we began working on the problem in early 2009, other groups had already succeeded in making structures that could cloak objects in two dimensions. But accomplishing this same feat at optical wavelengths and in three dimensions requires a bit more planning.

For design guidelines, we relied on work done by metamaterials theorists, such as Pendry at Imperial College and Ulf Leonhardt at the University of St. Andrews, in Scotland, who have shown how to reverse engineer a metamaterial design from the properties you want it to have. The trick is to use coordinate transformations, which are a bit like those used to work out how mass distorts the fabric of space-time in Einstein's general relativity. These let you derive the structure of a metamaterial from the way you want it to affect the flow of light.

Thanks to direct laser writing, invisibility cloaks that can operate at visible wavelengths have become a reality. We haven't used them to make anything as large as a person invisible. However, we have used them to alter the appearance of smallish things. The 3-D "carpet cloak" [see images, "Gone in 5 Micrometers"] that we constructed is based on a restricted geometry, but it does work for visible light and over a large range of frequencies, and it can make a patch of curved floor (the carpet) look as if it were a flat metal mirror.

The metamaterials menagerie now includes a number of other creations that previously seemed impossible. Photonic crystals based on titanium dioxide that completely reflect visible light coming from any direction are one recent creation; they could be used to steer light emitted by LEDs. Pentamode mechanical metamaterials–solids that behave much like liquids–have also been made. These could be used to create an unfeelability cloak that yields to pressure, so that the presence of an object can't be detected by touch. We've also succeeded in making 3-D photonic quasicrystals, the optical counterpart to the strange physical structures for which Dan Shechtman won the Nobel Prize in Chemistry in 2011. Although we're still exploring applications for this exotic material, direct laser writing is the only way to make the complex underlying structures.

IN THE MIDST OF ALL THIS EXCITING FABRICATION WORK, another innovation has drastically changed the fabrication process. Early laser writing was limited by microscope optics: It was necessary for a glass slide to sit between the microscope's objective lens and the photoresist. That arrangement meant that metamaterials could be no more than about 100 micrometers thick.

But in 2012, a new approach, introduced by Nanoscribe, a company that developed out of research done at our lab, solved this issue. In immersion microscopy, the microscope's objective lens is coated with a droplet of oil that sits between the lens and a glass slide. Nanoscribe created a special photoresist with the right refractive index to replace that oil, so that the resist could be dropped directly onto the lens.

Without the aforementioned two-photon absorption, of course, this scheme wouldn't be a good idea at all. Photons coming out of the lens would cure the photoresist all along the beam line, causing the photoresist to stick to the lens and destroying the lens after its first use. But recall that with two-photon absorption, we can localize the curing process in three dimensions.

This "dip-in" approach also enables us to build structures on surfaces other than glass. And because the resist and the lens are no longer separated by a thick glass substrate, we can extend the focus a good 10 times as far into a sample, creating 3-D metamaterials arrays as tall as 1 mm. That's getting close to a height where we can begin thinking about constructing macroscopic metamaterials–objects that are large enough to hold in your hand–rather than just thin, delicate coatings.

Of course, there's still room for improvement. The resolution of direct laser writing is only barely sufficient to make light-manipulating metamaterials that can operate at visible frequencies. Some more-complex structures, such as forests of metal helices, are still out of reach, and making them will likely require new photoresists. But in principle at least, there is no obvious reason we won't succeed.

We'll also have to tackle the issue of writing speed. On that front, we've actually been making good progress. In research labs, the laser is fixed, and structures are drawn by moving the sample around using high-precision 3-D piezoelectric actuators. These are commonly used at speeds of about 100 micrometers per second. For many structures, that translates to half an hour or so of work to create a metamaterial with a 100- by 100-μm footprint. But recently, Nanoscribe and others have adopted 2-D galvanometer-based laser scanning systems that can write much faster, with speeds upwards of 1 meter per second. Using these lithography instruments, which are now commercially available, we can reduce the fabrication times by a factor of a hundred or more.

Metamaterials are just the start. With the recent speed boost and with further improvements to spatial resolution, we think that direct laser writing might one day compete with planar electron-beam lithography, which is used today to make the stencil-like masks that pattern circuits on logic and memory chips.

And there's more. By incorporating active elements, such as nanodiamonds engineered to emit single photons, we could even envision creating 3-D optical systems for chip-based quantum information processing.

We're only beginning to explore what can be done with these new fabrication tools. But in the future, there may be no limit to how sophisticated and intricately structured matter can become. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/metamaterials0214

IEEE SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

Joint Institute of Engineering

FACULTY POSITIONS AVAILABLE IN ELECTRICAL/COMPUTER ENGINEERING

Sun Yat-sen University & Carnegie Mellon University are partnering to establish the **SYSU-CMU Joint Institute of Engineering (JIE)** to innovate engineering education in China and the world. The mission of the JIE is to nurture a passionate and collaborative global community and network of students, faculty and professionals working toward pushing the field of engineering forward through education and research in China and in the world.

JIE is seeking **full-time faculty** in all areas of electrical and computer engineering (ECE). Candidates should possess a doctoral degree in ECE or related disciplines, with a demonstrated record and potential for research, teaching and leadership. The position includes an initial year on the Pittsburgh campus of Carnegie Mellon University to establish educational and research collaborations before locating to Guangzhou, China.

This is a worldwide search open to qualified candidates of all nationalities, with an internationally competitive compensation package for all qualified candidates.

PLEASE VISIT: **jie.cmu.edu** for details

SHUNDE INTERNATIONAL

Joint Research Institute

RESEARCH STAFF POSITIONS AVAILABLE IN ELECTRICAL/COMPUTER ENGINEERING

SYSU-CMU Shunde International Joint Research Institute (JRI) is located in Shunde, Guangdong. Supported by the provincial government and industry, the JRI aims to bring in and form high-level teams of innovation, research and development, transfer research outcomes into products, develop advanced technology, promote industrial development and facilitate China's transition from labor intensive industries to technology intensive and creative industries.

The JRI is seeking **full-time research faculty** and **research staff** that have an interest in the industrialization of science research, which targets electrical and computer engineering or related areas.

Candidates with industrial experiences are preferred.

Applications should include a full CV, three to five professional references, a statement of research and teaching interests, and copies of up to five research papers.

Please submit the letters of reference and all above materials to the address below.

Application review will continue until the position is filled.

EMAIL APPLICATIONS OR QUESTIONS TO: **sdjri@mail.sysu.edu.cn**

SUN YAT-SEN UNIVERSITY Carnegie Mellon University

Faculty Positions - Hamad bin Khalifa University

Hamad bin Khalifa University (HBKU), a member of Qatar Foundation for Education, Science and Community Development, is an emerging research university that offers graduate research and educational programs in a unique research education model for world-class higher education. It is innovative, collaborative, and international, breaking with tradition by establishing interdisciplinary graduate colleges that will offer an array of research education Master's and Doctoral programs and conduct original, cutting-edge research.

The College of Science, Engineering, and Technology (CSET), a newly established college within HBKU, aims to be a world-class multidisciplinary college that will advance knowledge and nurture leaders and innovators, positively impacting and contributing to the development of Qatar, the region, and the world. CSET has established four divisions: Information and Communications Technologies, Sustainable Development, Life Sciences, and Engineering and Logistics Management.

HBKU and CSET are currently inviting applicants to be founding faculty members at all levels (Assistant, Associate, and Full Professor) in all areas of Engineering, Life Sciences, and Computer Sciences. Successful candidates must have an earned PhD degree from an accredited university, a demonstrated ability for research, and a commitment to graduate teaching and program development.

This is a great and unique time to consider joining HBKU and CSET as founding members. The University and College offer unprecedented opportunities for professional enrichment and personal fulfillment, with ample research funding opportunities.

HBKU offers an attractive compensation package that includes a tax-free salary and additional benefits such as furnished accommodation, annual paid leave, medical insurance, etc.

Candidates should apply via email by sending a cover letter, résumé (including the names and contact information of at least three references), a research statement, and a teaching statement (all in PDF format) to Professor Mounir Hamdi, Dean of the College of Science, Engineering, and Technology, at **dean.cset@qf.org.qa.**

For more information on Hamad bin Khalifa University,
visit **www.hbku.edu.qa.** For more information on Qatar Foundation,
visit **www.qf.org.qa.**

hbku.edu.qa

مؤسسة قطر Qatar Foundation

جامعة حمد بن خليفة HAMAD BIN KHALIFA UNIVERSITY

NAZARBAYEV UNIVERSITY

Faculty positions in Robotics and in Computer Science

SCHOOL OF SCIENCE AND TECHNOLOGY

NAZARBAYEV UNIVERSITY

ASTANA, KAZAKHSTAN

Nazarbayev University is seeking highly qualified full-time faculty at all ranks to join its rapidly growing programs in Robotics and Computer Science in the School of Science & Technology. Successful candidates must have an earned Ph.D. degree from an accredited university, excellent English-language communication skills, a demonstrated ability for research, and a commitment to graduate and undergraduate teaching and program development.

Launched in 2010 as the premier national university of Kazakhstan, NU's mandate is to promote the emergence of Astana as the research and educational center of Eurasia. The strategic development of this English-language university is based on the Western model via partnerships with top ranking world universities.

All suitable candidates will be reviewed. Applications are particularly encouraged from candidates with research interests that align with our focus areas of Embedded Systems, Industrial Automation and Manufacturing (Department of Robotics) and Computer Systems, Intelligent Systems, Mobile Computing, Information Security, and Software Engineering (Department of Computer Science).

Benefits include a competitive salary, international health care coverage, housing (based on family size and rank), child educational allowance, and home-leave travel twice per year.

To Apply: applicants should send a detailed CV, including qualifications, experience, and list of publications to sst@nu.edu.kz. Review of applications will begin immediately.

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IEEE Advancing Technology for Humanity

IEEE Student Job Site

ShanghaiTech University Faculty Search

The newly launched *ShanghaiTech University* invites *highly qualified* candidates to fill multiple tenure-track/tenured faculty positions as its core team in the School of Information Science and Technology (SIST). Candidates should have exceptional academic records or demonstrate strong potential in cutting-edge research areas of information science and technology. They must be fluent in English. Overseas academic connection or background is highly desired.

ShanghaiTech is built as a world-class research university for training future generations of scientists, entrepreneurs, and technological leaders. Located in Zhangjiang High-Tech Park in the cosmopolitan Shanghai, ShanghaiTech is ready to trail-blaze a new education system in China. Besides establishing and maintaining a world-class research profile, faculty candidates are also expected to contribute substantially to graduate and undergraduate education within the school.

Academic Disciplines: We seek candidates in all cutting edge areas of information science and technology. Our recruitment focus includes, but is not limited to: computer architecture and technologies, nano-scale electronics, high speed and RF circuits, intelligent and integrated signal processing systems, computational foundations, big data, data mining, visualization, computer vision, bio-computing, smart energy/power devices and systems, next-generation networking, as well as inter-disciplinary areas involving information science and technology.

Compensation and Benefits: Salary and startup funds are highly competitive, commensurate with experience and academic accomplishment. We also offer a comprehensive benefit package to employees and eligible dependents, including housing benefits. All regular ShanghaiTech faculty members will be within its new tenure-track system commensurate with international practice for performance evaluation and promotion.

Qualifications:

- A detailed research plan and demonstrated record/potentials;
- Ph.D. (Electrical Engineering, Computer Engineering, Computer Science, or related field);
- A minimum relevant research experience of 4 years.

Applications:

Submit (in English) *a cover letter, a 2-page research plan, a CV plus copies of 3 most significant publications, and names of three referees* to: **sist@shanghaitech.edu.cn** by March 31st, 2014 (until positions are filled). *For more information, visit http://www.shanghaitech.edu.cn.*

School of Electrical & Computer Engineering
College of Engineering

The University of Oklahoma School of Electrical and Computer Engineering invites applications for a tenure-track Assistant Professor position. Candidates are sought in the area of electric energy systems and smart grid with a particular focus on the power system. Outstanding candidates in other related areas including control systems, power electronics, renewable energy and distributed generation are also encouraged to apply.

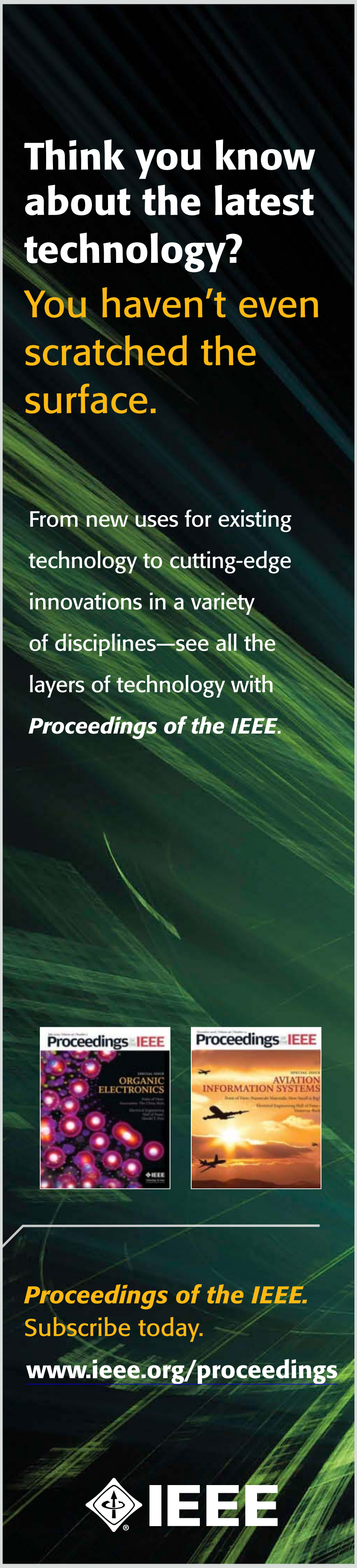
The position requires an earned doctorate in electrical and/or computer engineering, or a closely related discipline. Exceptional candidates with a record of professional achievement sufficient for tenured or tenure-track appointment at the rank of Associate Professor will also be given serious consideration. The successful candidate will be expected to: (a) contribute to research efforts in the development of smart grid technology, control of renewable energy resources and enhancement of grid security; (b) teach at both the undergraduate and graduate levels.

Established in 1890, the University of Oklahoma is a comprehensive public research university offering a wide array of undergraduate, graduate and professional programs and extensive continuing education and public service programs. The newly completed Devon Energy Hall, a 100,000 square foot state-of-the-art building containing research laboratories, offices, and classrooms, is the new home to the School of Electrical and Computer Engineering. Energy has long been a cornerstone of the economy of Oklahoma, and the University has long-term, energy-related research programs ongoing.

Candidates should submit a letter of application, curriculum vitae, teaching and research statements, and the names of three references to ecesearch@ou.edu, or for questions you may contact:

Ms. Cathy Trujillo, Business Manager
OU School of Electrical and Computer Engineering
110 W. Boyd St., Rm. 150
Norman, OK 73019-1102
Voice: 405.325.4723

Electronic submission in PDF format is preferred. Review of applications will begin immediately and continue until the position is filled. Minorities and women are especially encouraged to apply.The University of Oklahoma is an Affirmative Action/Equal Opportunity Employer and encourages diversity in the workplace.



HSR

HOCHSCHULE FÜR TECHNIK RAPPERSWIL

FHO Fachhochschule Ostschweiz

The Electrical Engineering Department of the University of Applied Sciences of Eastern Switzerland in Rapperswil (HSR) is looking for a

PROFESSOR OF ELECTRICAL ENERGY SYSTEMS,

starting September 1, 2014.

We expect the ability to teach power electronics, power distribution networks, three-phase technology and electrical drives at the Bachelor's level in German and possibly also in English. We also expect the ability to manage student teams during their term and/or bachelor projects. Furthermore, we expect the ability and the interest to perform externally sponsored research and development within the framework of an existing institute at the HSR.

We expect a university degree in Electrical Engineering and several years of relevant industrial experience in, for example, power electronics research and development or planning and implementation of state of the art power distribution networks. Furthermore, we expect a well-established professional network in Switzerland.

We expect in-depth knowledge about renewable power sources and the resulting demands that these sources place on a power distribution network. We expect an understanding of the state-of-the-art in the smart grid field and a proven ability to apply these theories in practice.

We expect experience in gaining external grants and/or industry contracts and a proven track record of successfully lead research and development projects.

We expect the ability and the interest in teaching undergraduates at a University of Applied Sciences and a willingness and interest to work on curriculum and/or department and/or university development.

We offer an interesting and challenging job at the forefront of technology. The HSR has very well equipped laboratories and offers a large degree of freedom in teaching and research. Furthermore, we are centrally located in the picturesque town of Rapperswil, between the train station and the shores of beautiful Lake Zürich.

Please send your application as one PDF to professuren@hsr.ch. The deadline for this position is February 22, 2014. Inquiries about this position should be directed to the head of the Electrical Engineering Department, Prof. Dr. Heiner Prechtl, +41 (0)55 222 45 94.

The **University of Applied Sciences of Eastern Switzerland HSR** educates about 1500 bachelor and master students in technology and IT, architecture, civil engineering and spatial planning. The CAS and MAS courses are aimed at industry practitioners. Through its 18 institutes, which are performing research and development, the HSR is well connected with industry and public institutions.

Oberseestrasse 10 ■ Postfach 1475 ■ CH-8640 Rapperswil
www.hsr.ch

香港城市大學
City University of Hong Kong

Worldwide Search for Talent

City University of Hong Kong is a dynamic, fast-growing university that is pursuing excellence in research and professional education. As a publicly-funded institution, the University is committed to nurturing and developing students' talents and creating applicable knowledge to support social and economic advancement. Currently, the University has six Colleges/Schools. Within the next two years, the University aims to recruit **100 more scholars** from all over the world in various disciplines, including **business**, **creative media**, **energy**, **engineering**, **environment**, **humanities**, **law**, **science**, **social sciences**, and other strategic growth areas.

Applications and nominations are invited for:

Head *[Ref. A/129/36]*
Department of Mechanical and Biomedical Engineering

The Position

Reporting to the Provost through the Dean of College of Science and Engineering, the Head of Department will provide leadership and strategic direction in research and professional education for the Department. The Head will encourage and promote academic excellence, and steer the Department to enhance the mission and vision of the University in alignment with the University's Strategic Plan.

The Person

A doctorate degree with strong academic and professional qualifications, a distinguished record of teaching, research and scholarship, and substantial relevant experience in tertiary education; outstanding management effectiveness; commitment to teamwork; and strong communication and networking skills to build and nurture internal and external contacts to the benefit of the Department.

Salary and Conditions of Service

The appointee will be offered appointment to an academic rank commensurate with qualifications and experience. The Headship appointment will be on a concurrent basis for an initial period of three years. Remuneration package will be attractive and driven by market competitiveness and individual performance. Excellent fringe benefits include gratuity, leave, medical and dental schemes, and relocation assistance (where applicable).

Information and Application

Further information on the post and the University is available at http://www.cityu.edu.hk, or from the Human Resources Office, City University of Hong Kong, Tat Chee Avenue, Kowloon Tong, Hong Kong [Email : haby.lee@cityu.edu.hk/Fax : (852) 2788 1154 or (852) 3442 0311].

Please send the nomination or application with a current curriculum vitae to Human Resources Office, City University of Hong Kong, Tat Chee Avenue, Kowloon Tong, Hong Kong, or e-mail to "haby.lee@cityu.edu.hk". **Applications and nominations received before 28 February 2014 will receive full consideration.** The University's privacy policy is available on the homepage.

The University also offers a number of visiting positions through its "CityU International Transition Team" scheme for current graduate students, postdoctoral scholars, and for early-stage and established scholars, as described at http://www.cityu.edu.hk/provost/cityu_international_transition.htm.

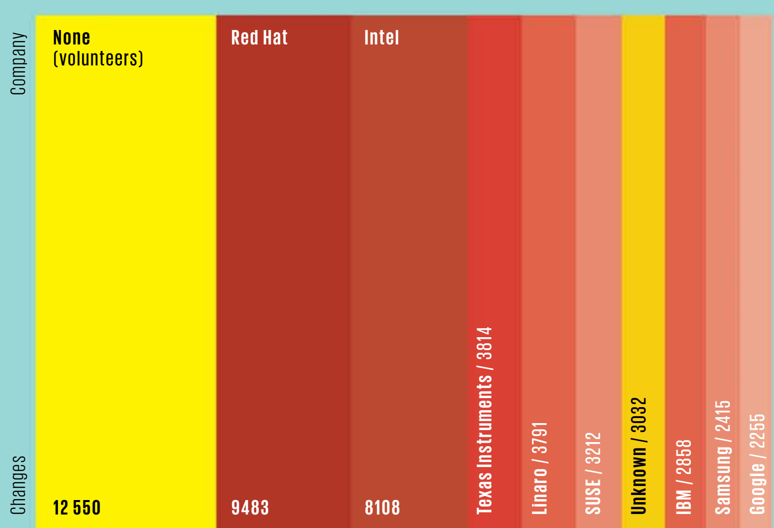
City University of Hong Kong is an equal opportunity employer and we are committed to the principle of diversity. We encourage applications from all qualified candidates, especially those who will enhance the diversity of our staff.

City University of Hong Kong was ranked 5th among the world's top 50 universities under the age of 50 in the *Quacquarelli Symonds* 2013 survey
http://www.cityu.edu.hk

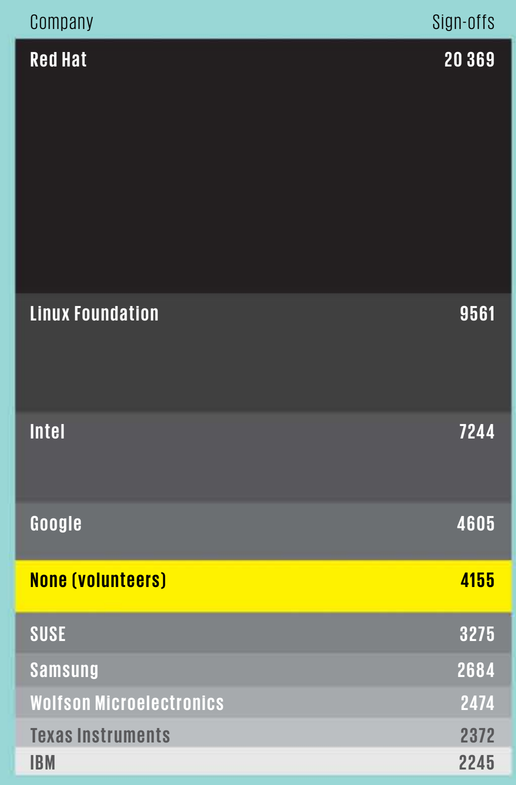
DATAFLOW_

WHO'S WRITING LINUX?
CORPORATE-SPONSORED PROGRAMMERS DOMINATE

About once a year, the Linux Foundation analyzes the online repository that holds the source code of the kernel, or core, of the Linux operating system. As well as tracking the increasing complexity of the ever-evolving kernel over a series of releases from versions 3.0 to 3.10, the report also reveals who is contributing code, and the dominant role corporations now play in what began as an all-volunteer project in 1991. **—STEPHEN CASS**

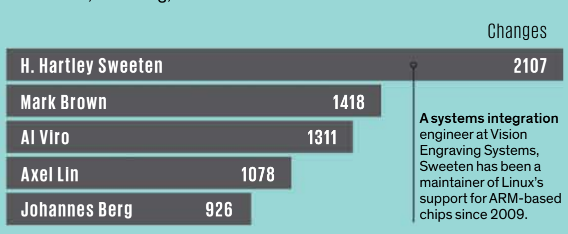


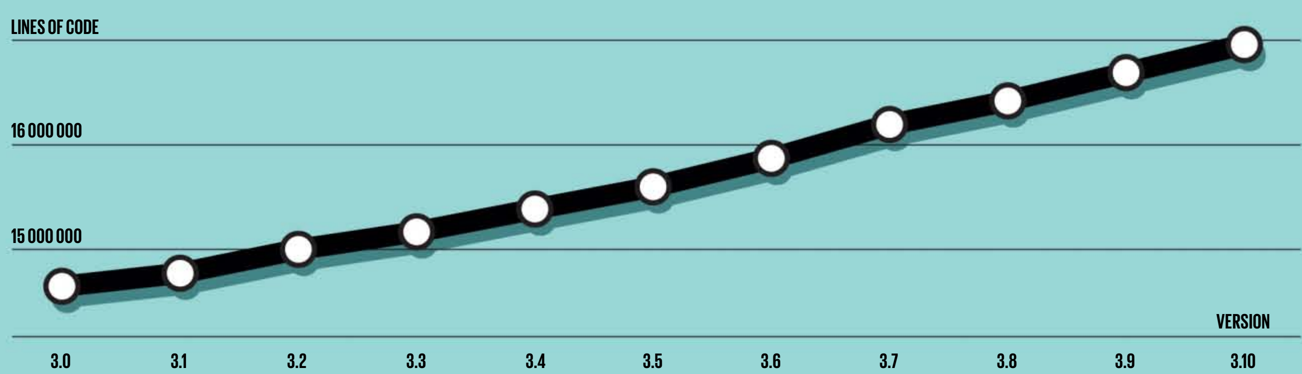
WHO'S PAYING THE BILLS? While volunteer contributors still represent a plurality among developers, over 80 percent of code is contributed by people who are paid for their work. The Linux Foundation notes that contributions have been increasing from companies that make mobile and embedded systems, such as Linaro, Samsung, and Texas Instruments.



THE GATEKEEPERS Contributions from individual developers must have sign-offs before being incorporated into the official kernel code. Here corporate employees truly dominate, with just over 5 percent of approvals by volunteers.

THE AUTHORS These are the programmers who have contributed the most code updates to versions 3.2 through 3.10.





THE GROWING KERNEL The increasing size of the Linux kernel is due to the incorporation of significant new features, including a file system optimized for solid-state drives and support for the 64-bit ARM microprocessors used in embedded and mobile devices.

SOURCE: "LINUX KERNEL DEVELOPMENT: HOW FAST IT IS GOING, WHO IS DOING IT, WHAT THEY ARE DOING, AND WHO IS SPONSORING IT," LINUX FOUNDATION, 2013.

ILLUSTRATION BY MCKIBILLO