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FOR THE TECHNOLOGY INSIDER | 02.13

Sound Design

HOW GEOFF MARTIN IS HELPING BANG & OLUFSEN HIT THE HIGH NOTES
DREAM JOBS P. 34

IEEE

FEATURES_02.13

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ON THE COVER **Photograph for *IEEE Spectrum* by Henrik Sørensen**

PHOTOGRAPH BY **Antoine Doyen**

DEPARTMENTS_02.13

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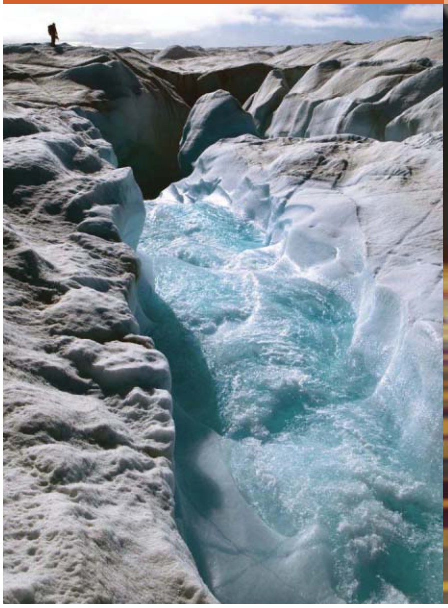

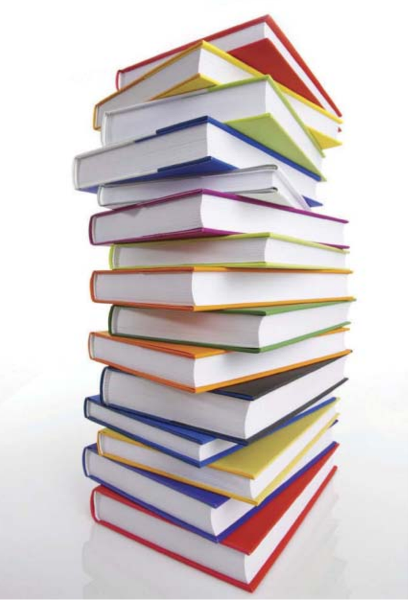

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RAPID DNA ANALYSIS IS ON THE HORIZON Today, DNA analysis takes weeks to produce results and must be done in a lab. With a new system, analysis takes less than 2 hours and can be done in the field. The system was presented at the IEEE Homeland Security Conference in November.

IEEE SIGHT GETS OFF THE GROUND Members are working on dozens of projects to help underserved populations through sustainable technologies that are tailored to those communities. IEEE has launched a program that will be able to provide the groups with the support and tools they need to succeed.

RADARCON TO FOCUS ON THE ARCTIC As the Arctic becomes more accessible, radar's role in the region's development is growing. This year's IEEE Radar Conference will focus on that role, the technical challenges involved, and the emerging technologies that will support it.

FROM LEFT: ENVIRONMENT IMAGES/GETTY IMAGES; JAKOB NIELSEN; ISTOCKPHOTO

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BACK STORY_

The Elements of Style

IEEE Spectrum's art staff and the photographers they hire make it all look magically easy. But in fact, getting many of the photos you see as you leaf through these pages is anything but. Take the photo of Marcia Lee, one of the people we profile in this issue's Dream Jobs special report. She's a programmer at the Khan Academy. But because her work serves many young kids who are still learning their reading, writing, and arithmetic, we wanted to give her the air of an old-time schoolteacher in our photo. How exactly do you make that happen?

In this case, achieving the proper image required more than just a skilled photographer. It also demanded the hard work of wardrobe and prop stylist Tietjen Fischer [above], who is also a hair and makeup artist. The day before the shoot, Fischer combed through the Prop House, just south of San Francisco, for suitable objects to decorate the scene. "I know the Prop House like the back of my hand," says Fischer. That's no small accomplishment, this prop-rental facility being as large as a typical Costco and stuffed to the ceiling with art, memorabilia, signage, appliances, sporting goods, furniture, and bric-a-brac.

Fischer packed her Honda Element full of items chosen to temporarily transform a Silicon Valley photo studio into an old-school classroom. Then she had to put Lee, who doesn't use makeup and typically wears T-shirts and jeans to work, in character. But Fischer is used to such assignments. "I've done everything up to special effects," she says. "I can even simulate bleeding from an open chest wound."

We don't think we'll need that particular talent anytime soon. But then again, we never thought we'd need to turn a Stanford-educated programmer into a schoolmarm. That's part of the challenge and the fun: Every month brings new and often odd missions—and a crew of talented and dedicated people to complete them. ■

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PHOTOGRAPH BY **Gabriela Hasbun**

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R. Les Cottrell

In his 43-year career, Cottrell has racked up a number of firsts. He worked with the Nobel Prize–winning team that discovered the quark. He helped establish the first Internet connection to China and worked on the first website in North America. Now at the SLAC National Accelerator Lab, in California, he runs the first global Internet monitoring system, which he describes in "Pinging Africa" [p. 52].

Bill Cramer

"I think of myself as more of an impressionist than a realist," says Cramer, who photographed engineer-turned-teacher Simon Hauger [p. 36]—an assignment he found easier than many. When photographing people where they live or work, Cramer says, "In most cases I find myself making something out of nothing. But this time, there were tools, gadgets, and cool backgrounds everywhere we turned."

Phil Lapsley

Lapsley, an electrical engineer with an MBA, founded two tech companies near San Francisco before becoming a consultant for McKinsey & Co., accomplishments he cites to "look like an upstanding member of society." In his spare time, though, he was researching and writing *Exploding the Phone*, a just-published book about the original outlaw hackers, which we have excerpted in "Phreaking Out Ma Bell" [p. 28].

Dave Levitan

Levitan got the cold truth behind "Laser Eyes Spy a Big Melt in the Arctic" [p. 7] at the American Geophysical Union meeting in San Francisco, last December. He reported on the remote sensing systems involved because sea ice "is becoming more and more obviously absent from the world…and I knew it was important to look at ways of keeping track of that."

Henrik Sørensen

Danish photographer Sørensen shot Bang & Olufsen's Geoff Martin for this issue [cover and p. 40]. His clean style echoes B&O's product design as represented by the current and prototype speakers in the portraits. For one photo, he used multiple exposures and a flashlight to link Martin to the speakers with a streak of light. "I wanted to illustrate the unphotographable sound wave," says Sørensen.

Andrew J. Steckl

Steckl is a professor of electrical engineering at the University of Cincinnati. An IEEE Fellow, he has been a member of IEEE since his college days. After early work fabricating conventional, rigid semiconductors, he's become a believer in alternative materials, such as paper [see "Circuits on Cellulose," p. 46]. "It's amazing what you can do when you combine cheap materials and hard thinking," he says.

PHOTO-ILLUSTRATIONS BY **Gluekit**

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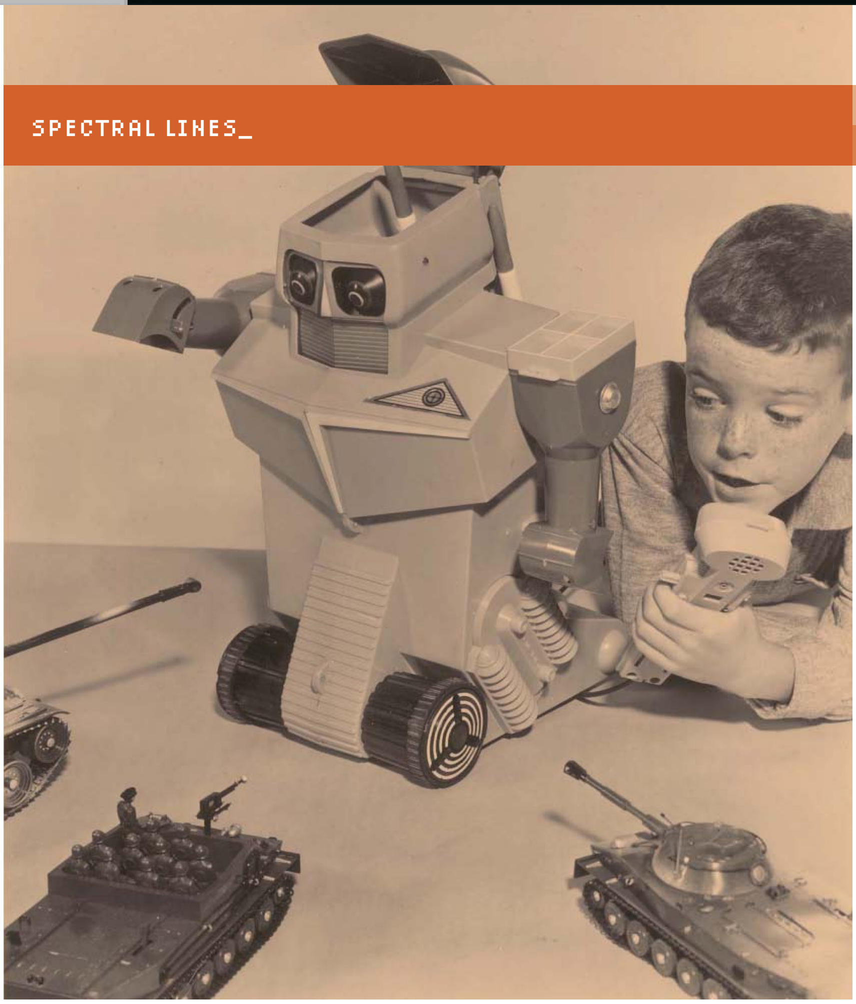


Hands Off Hands-On

DARPA shouldn't fund programs in primary or secondary schools, even if they help improve STEM education

IEEE Spectrum's annual Dream Jobs report, in this issue, is our modest contribution to Engineers Week, which begins this year on 17 February. According to the U.S.-based National Engineers Week Foundation, we are all "challenged to prepare the next generation of talent by helping to remove the social, educational, and economic barriers that deter young students from engineering and technology education and careers." Few would argue with that noble sentiment. But there's been quite a bit of argument this past year over one controversial approach to advancing this cause. ● What sparked the brouhaha was a seemingly innocuous U.S. government grant to O'Reilly Media's *Make* magazine division, to help create 1000 high school "makerspaces" over the next four years. These in-school facilities are to be modeled on hackerspaces—places that house informal groups of technically minded people who work on various wacky and not-so-wacky projects with little if any commercial or governmental involvement. Indeed, the whole hackerspace movement has traditionally been very antiauthoritarian. ● So it rubbed many of these hackers (or "makers," as *Make* likes to call them) the wrong way when O'Reilly Media accepted this funding, which comes from the U.S. Defense Advance Research Projects Agency's Manufacturing Experimentation and Outreach program, part of a larger initiative to improve the design of military vehicles.

Make's revelation of its DARPA funding prompted Mitch Altman, a founder of San Francisco's Noisebridge hackerspace, to declare that he would no longer help with Maker Faire, for example. Soon after, Fiacre O'Duinn, who works with the Ontario Library and Information Technology Association, wrote a scathing critique of O'Reilly's military dalliance on his blog, Library Cult.

Two days after that, Dale Doherty, head of O'Reilly's *Make* division, attempted to address these concerns on his magazine's blog. There he explained, for example, that DARPA would not be asserting ownership of the intellectual property that came out of these hackerspaces and that the students and their teachers, not DARPA, would decide what they wanted to build. "The goals of *Make* and DARPA align in this instance because we have a mutual interest in seeing a more diverse pool of young people become scientists, engineers, programmers," Doherty wrote.

And not all members of the Noisebridge hackerspace shared Altman's qualms. Some said they were just happy that *some* arm of the U.S. government was keen to boost student access to the tools and educational opportunities these facilities would bring.

To my mind, the answer here is crystal clear—it's the question that's muddy. Are we asking whether working with the military is good or bad? If that's the question, reasonable minds must agree to disagree. But it seems to me the issue here is narrower: Should military agencies involve themselves with primary- or secondary-school education? And to that question, I believe the answer is no. Heck, no.

Students of those ages are busy learning a lot of things, among them where they stand on the use of violence to resolve conflict. It's one of the toughest questions many of them will have to ponder. In an open and free society, we must give these young people time to mature before we can expect them to come to their own conclusions. They need time to learn about such figures as Adolf Hitler and Mohandas Gandhi, for example, before we ask them to decide whether participating in a program with military links meshes with their personal ethics. Telling students for whom it doesn't that they'll have to opt out of their school's new digital-fabrication lab would be discriminatory, even divisive.

We already have one gaping digital divide that needs mending. Let's not create another. —DAVID SCHNEIDER

HULTON ARCHIVE/GETTY IMAGES

NEWS

THE EXTENT OF ARCTIC SEA ICE IN SEPTEMBER WAS 700 000 SQUARE KILOMETERS BELOW THE PREVIOUS MINIMUM.

GREENLAND BLUES: Sensors are spying signs of climate troubles, such as this glacial lake in Greenland.

THE ASAHI SHINBUN/GETTY IMAGES

LASER EYES SPY A BIG MELT IN THE ARCTIC

Airborne altimeters yield a disturbing picture of polar ice loss

SCIENTISTS FROM THE U.S. National Oceanic and Atmospheric Administration didn't pull any punches when they released the latest Arctic Report Card in early December. In 2012, levels of snow cover and sea ice were both at record lows, while surface melting of the massive Greenland ice sheet increased, despite temperatures in the region that were "unremarkable relative to the last decade." In short, the Arctic seems to be deteriorating faster than scientists thought it would.

The latest results rely heavily on a NASA mission called IceBridge and its suite of sensors. IceBridge, an operation involving the P-3B, the DC-8, and other airplanes, is intended to "bridge" the gap between ICESat, a satellite that operated between 2003 and 2009, and ICESat-2, scheduled for launch in 2016.

The primary instrument used by both ICESat missions, as well as IceBridge aircraft, are laser altimeters. IceBridge uses »

DATA BYTE

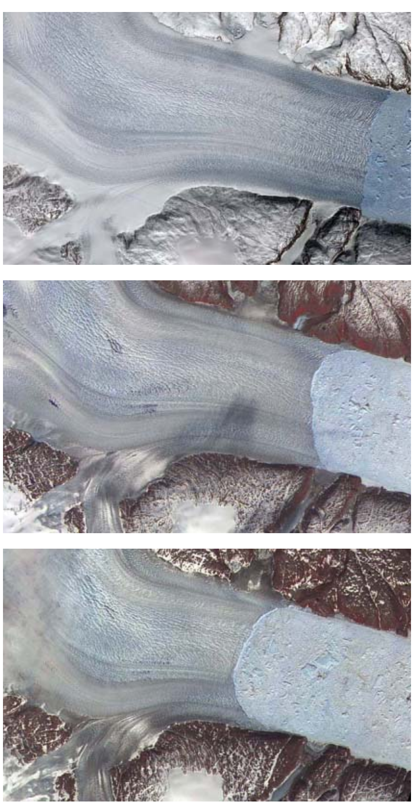
2.8 million km³

Amount of ice in Greenland. If it all melted, it would raise sea level by 6 meters.

several versions of such altimeters; the Airborne Topographic Mapper, for example, on both P-3B and DC-8 planes, can measure topography below the plane to within 10 centimeters. (ICESat-2 will do this one better with a multibeam laser altimetry system, which NASA says will improve ice elevation measurements as well as the detection of ice leads, which are basically cracks in sea ice.)

A more advanced instrument, a scanning lidar, can collect 10 000 data points every second as it scans a wide swath of ice from beneath a smaller aircraft. A different lidar device, used in IceBridge by researchers from the University of Texas at Austin, raises that to more than 2 million data points per second but is more constrained in its scanning width.

The planes also feature a number of radar instruments that let scientists characterize layers of ice all the way down to the bedrock beneath. The same trick doesn't work over floating ice, so each aircraft carries a gravimeter to determine how much water is below the ice.



RETREAT! Images from 2001, 2003, and 2005 [from top] show changes at the point where a glacier [left side, each image] breaks up and flows into the sea.

All this instrumentation has yielded some disturbing results recently. The extent of sea ice this year dropped down to 3.41 million square kilometers on 16 September, a remarkable 18 percent lower than the previous record set, in 2007. Further, the 2012 minimum was a full 49 percent below the 1979–2000 average sea ice cover. September ice levels seem to be dropping faster than those in the computer models, according to Andrew Barrett, a research scientist at the National Snow and Ice Data Center at the University of Colorado, in Boulder. However, Barrett says, this discrepancy is not statistically significant when the models are considered as a group.

In discussing some of the recent IceBridge data at the American Geophysical Union (AGU) meeting in December, Barrett asked what he called a "rather crass" and "somewhat simplistic" question: "When are we going to see an ice-free Arctic Ocean?" He then answered his own question, saying that fewer than 50 percent of the models show an ice-free Arctic before 2060. But he suggests that 2030 may be a reasonable guess, given most recent observations. (Researchers treat anything below 1 million km² as "ice-free.")

The question of when the ice will disappear entirely is not purely academic. It affects marine shipping routes, as well as coastal communities and wildlife.

If you're looking for more globally relevant implications of the remote sensing data, look to the melting Greenland and Antarctic ice sheets, which, unlike Arctic sea ice, will play the primary role in sea level rise in coming years. Modeling ice sheets is much more difficult than modeling sea ice; just in recent months, studies have suggested both an acceleration and a slowing of Greenland's sheet, and an accounting based on aerial photographs yielded the conclusion that the sheet has periods of rapid melting that come and go.

Satellite data suggest, however, that the last decade or so has seen some fairly dramatic melting. John Robbins, a principal scientist at NASA, presented research at the AGU that uses ICESat laser altimetry data to attempt to quantify ice loss from the "ice caps" around the Greenland sheet. The ice caps, he says, are "the little bits and pieces that are around the edges of Greenland. When we've analyzed ICESat up to this point, we've been focused mostly on the main sheet."

His analysis of more than 25 ice caps–based on changes in elevation of the caps measured by ICESat's Geoscience Laser Altimeter System–shows a combined loss of around 15 gigatons per year of ice (or about 16.7 cubic kilometers of volume). There are other ice caps to measure, so the final answer is most likely a bit higher.

"As an approximation, Greenland as a whole is losing something on the order of 200 gigatons per year," Robbins says. "So this is something on the order of maybe 8 to 10 percent of the total loss going on in the whole of Greenland." Only one of the 25 ice caps he initially sampled was found to be gaining any mass.

Combining IceSat and IceBridge has yielded a data set that shows an acceleration in Greenland ice loss, according to Beata Csatho, a geophysicist at the University of Buffalo, in New York. She estimates that the mass loss in the Greenland sheet will accelerate 22.1 km³ per year each year. The acceleration is probably slowing slightly, she says, but "there really is a potential for rapid ice loss." —DAVE LEVITAN

JESSE ALLEN/NASA EARTH OBSERVATORY (3)

RWE POWER

NIMBLE COLOSSUS: Turbines in a coal-fired generator near Cologne can shed 500 megawatts in 15 minutes.

QUICKER COAL POWER

Coal-burning generators improve their agility to compete with natural gas

In January, an 18-wheeler truck was scheduled to pull into Mexico City, nearing the end of an international road show spreading the gospel of General Electric's nimble new gas turbines. A key message was that GE's FlexEfficiency natural-gas-fired power plants can complement fluctuating wind and solar energy far better than their coal-fired brethren. The latter clearly need their own PR road show to shake their reputation as laggards when it comes to boosting or throttling back electric power generation. That's because engineering firms are improving the agility of coal-fired power plants, and the best are hot on the GE model's heels.

Consider the massive lignite-coal-burning power plant that German utility RWE Power started up near Cologne, Germany, in August 2012. Each of the dual 1100-megawatt steam turbines can ramp generation up or down by 500 MW in less than 15 minutes. While admittedly one-third slower than GE's new natural-gas plants, that rate is still twice as fast as the best achieved by recent gas-fired plants supplied by Siemens, and more than six times as fast as the average coal-fired plant running today.

Agility is a matter of life or death for coal-fired generators in Germany, says Mathias Hartung, who runs RWE's power-generation business. "Renewable energies always have priority on the grid in Germany, so conventional power plants have to adapt," he says. "Only a flexible power plant can survive in this environment."

According to Hartung, RWE is preparing a next-generation coal plant that will be even more agile than the Cologne plant–able to add or shed 600 MW in 15 minutes. That would close half of the gap between RWE's lignite-burning plants and GE's gas plants.

What accounts for the RWE plants' rapid improvement? The utility and Paris-based steam-turbine manufacturer Alstom maximized flexibility by using better materials in the plant's boiler and turbine and installing more sophisticated controls that regulate the turbine and keep it in sync with other power plant components.

The 170-meter-high boilers, for example, are the first to use tough T24 steel, thanks to novel welding techniques developed by RWE. They are thus able to absorb the internal strain caused by rapid changes in the lignite firing rate. "Compared to their predecessors, they are capable of withstanding up to twice as much thermal loading for the same level of aging," says Charles Soothill, chief technology officer at Alstom Thermal Power.

Controls informed by real-time sensor data, meanwhile, free the boilers and turbines from preset–and thus conservative–operating parameters. "Load changes are continuously optimized such that the maximum permissible stress in a component is approached but never exceeded," explains Soothill.

As Germany phases out nuclear power, keeping coal plants running will be a necessity, because natural gas is expensive there. And it's not just Germany. The International Energy Agency predicts that by the end of the decade, demand from India and China will push coal to surpass oil as the world's No. 1 energy source.

More coal burning will keep the lights on, but it won't do the climate any good. That's one thing natural-gas plants can still crow about. GE estimates that one of its FlexEfficiency plants will emit 2.6 million fewer metric tons of carbon per year than would a coal plant of comparable size. –PETER FAIRLEY

NEWS

From This Day, Forward

A few examples of the Stratasys 3D Printer line.

3D technology is all around us. It's changing how we design and manufacture products, make movies, heal our bodies and interact with the world. Work that used to take place on a page or screen now reaches into space. And faster than ever before, 3D technology is transforming our world.

To see the impact of 3D, look to the realm of design. Designers led the way in embracing 3D CAD and then 3D printing, incorporating more and more physical models into their iterations and thinking with their heads and their hands. And they've reaped the benefits: design problems surface sooner and solutions are less costly. Inspiration happens faster. Ultimately, products are better and consumers are happier. Black & Decker makes a safer tree trimmer and Lamborghini makes a faster car because reviews and trials are more frequently executed on models very much resembling a final product.

Now, 3D printing applications are expanding from design into production, and freeing manufacturers to build without traditional restrictions. DDM stands for direct digital manufacturing, a way to produce a finished product, part or tool straight from a computer design. More importantly, DDM means the rewards of faster, leaner, smarter methods are coming to the production floor. When we at Stratasys (and publications like The Economist, Forbes and The New York Times) call 3D printing "the next industrial revolution," we're not exaggerating.

A hundred years ago, the assembly line changed the world with mass production. It brought luxuries to the middle class, good wages to workers and economies of scale to investors. Today, companies like BMW already know that DDM is mass production's heir apparent. One factory-floor fixture, a nameplate-application device, offers an elegant example. Liberated

ADVERTISEMENT

Left: This rover includes about 70 FDM parts, including housings, vents and fixtures. Right: A pediatric engineering research lab has developed and 3D-printed custom devices for their smallest patients.

from tooling constraints, BMW engineers reduced the device's weight by half and replaced its blocky stock-metal handles with ergonomic grips – a great relief to workers who might lift the fixture hundreds of times per shift.

Today, NASA can shape a complex, human-supporting vehicle suitable for Martian terrain, despite the fact that its parts are too complex to machine, too rapidly iterated to outsource and too customized for traditional tooling.

In a 3D world, we leave behind injection molding, casting and machining, gaining economy without the scale. 3D printing leads us beyond mass production and into mass customization. It's how a researcher at a Delaware hospital creates a durable ABS-plastic exoskeleton customized to perfectly fit one child, Emma, allowing her to play, explore and hug for the first time. Then that researcher can make a 3D-printed exoskeleton to fit a different child. And another. And a dozen more. Now 15 children with rare disorders can raise their hands because of mass customization.

Ideas born today – your ideas – are freer to solve problems faster than ever before. Now, two innovators who helped spark this revolution have fused to lead the charge together, and more great changes are at hand.

Welcome to the new Stratasys, leader of the next industrial revolution.
—DAVID REIS, STRATASYS CEO

TIM ROBBERTS/GETTY IMAGES

PLUGGING IN TO PLANT ROOTS

Marsh grasses can power small fuel cells

Cast-off electrons in a plant's roots can provide electricity, a Dutch team reports. Now, through a spin-off company, it hopes to grow grassy generators on rooftops and promote decentralized electrical production in wetlands in developing countries.

Plants exude a variety of waste products that microbes consume, such as glucose, acetate, butyrate, and propionate. The underground interaction leaves spare electrons in the surrounding soil and water, which researchers–led by Bert Hamelers at Wageningen University, in the Netherlands–began tapping in experiments in 2007. They were already working on using so-called microbial fuel cells (MFCs) to treat wastewater when they realized that plant roots improved the performance of the fuel cells.

In a series of experiments, the team measured the performance of its fuel cells as used in conjunction with plants. When bacteria consume a plant's organic waste, they release electrons, carbon dioxide, and hydrogen ions. The plant-microbial fuel cell passes the ions–but not the electrons–through a membrane to an oxygen-rich cathode, creating a potential difference. Wageningen environmental technologist Marjolein Helder and her colleagues built a pilot plant on the roof of a building at the university that has produced an average of about 0.44 watts per square meter of planted area, which they report in a forthcoming article in *Biotechnology for Biofuels*. "With the power output we've achieved, we don't have an economically practical green electricity technology... but we'll definitely be able to compete soon," Helder says.

She's comparing the plant-microbial fuel cell to other biomass energy technologies, such as growing trees and burning the wood or fermenting waste biomass into a liquid fuel. The amount of energy per unit land area the team has achieved is already the same order of magnitude as that of at least one estimate of old-fashioned wood-burning, of about 0.7 W/m². The advantage of plant-MFCs is that although they'll require occasional maintenance, they won't require harvesting or transporting wood.

Helder calculates that the system should be able to approach a maximum power density of around 3.2 W/m². The team hopes to get closer to that figure by

> Some soil bacteria build microbial "nanowires" with conductivities comparable to those of synthetic metal nanowires.

altering the size and shape of the fuel cell electrodes in order to reduce their internal resistance. Its last attempt at such modifications doubled performance from 0.22 to 0.44 W/m². Other possible changes include using a different plant growth medium to direct more of the waste electrons to the electrodes, and improving the substrate on which the microbes feed.

The installation costs are still higher than those of other renewable technologies such as windmills or solar panels, says bioelectrochemist Feng Zhao of the Chinese Academy of Sciences, in Xiamen. He also notes that rooftop systems will work only in places that can count on adequate rainwater and little evaporation, such as the Netherlands. The next necessary step, he says, is to drop the capital costs. Helder says her pilot plant cost around €600 (about US $780) per square meter to install but that most of that cost was labor. She is aiming for under $40 per square meter.

Still, existing plant-MFC technology is probably already good enough to power environmental sensors in remote locations, Zhao says. "The voltage itself can…reflect the plant health or soil microbial activity," he adds, so MFCs could also monitor the very plants that power them. Some companies and laboratories have already begun using tiny forest-monitoring sensors powered by a potential difference between trees and the soil around them.

For now, Helder's spin-off company, Plant-e, is focusing on a tabletop toy: a plant-microbe fuel cell that powers a spinning globe. The toy may raise awareness and a little money, but the real goal is to commercialize larger installations, she says. If the toy market can power the start-up long enough to turn a profit or pick up a bigger investment, Plant-e will expand from its rooftop design to one that could work on an industrial scale in wetlands. "It could be a source of decentralized electricity in developing countries," Helder says. —LUCAS LAURSEN

NEWS

GRAPHENE GOES THE DISTANCE IN SPINTRONICS

Experiments push electron-spin signals to record lengths

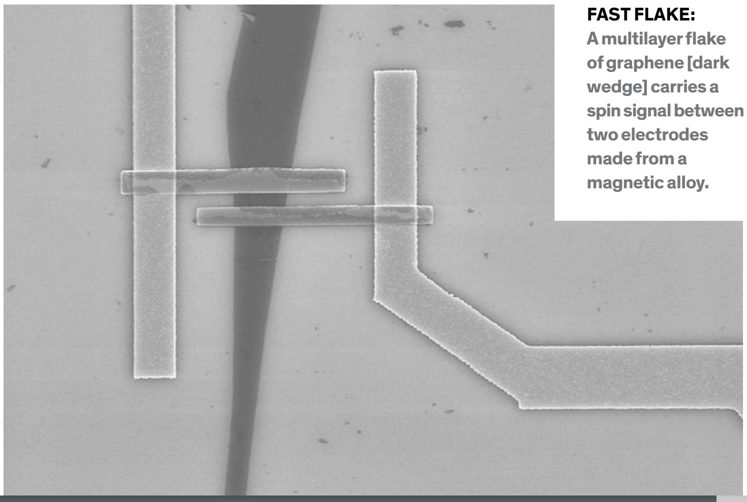
THE FUTURE OF COMPUTING might just come down to the honeycomb. Researchers have pushed graphene's ability to carry information using the spin of electrons to record distances. The results mean that the material—composed of honeycomb-like sheets of carbon atoms—may be ideal for future devices that use spin instead of electrical current to perform computations and carry signals.

Spin is a quantum mechanical property of many particles that responds to magnetic fields and corresponds to an intrinsic angular momentum. It can be a useful binary signal, because in the presence of a magnetic field it can be oriented in either of two ways—either parallel or antiparallel to the magnetic field.

Harnessing spin is nothing new—it is already used over short, vertical distances to store and read data in hard disks. But many researchers hope to find a way to use spin over longer distances. That could pave the way for new kinds of devices that perform computations using much less power than existing CMOS devices.

Such "spintronic" devices would bear some structural similarity to the traditional transistor, with an input and an output—sort of like the transistor's source and drain—connected by an electron-carrying channel. However, the signal involved is carried by the magnetization of the channel rather than the flow of current. In a spintronic device, the input and output areas are magnetic. When a voltage is applied at the input, it skews the distribution of electron-spin orientations in the channel so that they more or less reflect the magnetization of the input. In one recently proposed spintronics device, this spin signal can then be used to alter the magnetization of the device's output.

But the success of any spintronic device hinges in large part on what happens to spins once they make it into the channel. Interactions with »



FAST FLAKE: A multilayer flake of graphene [dark wedge] carries a spin signal between two electrodes made from a magnetic alloy.

YUNFEI GAO AND YURI KUBO

DATA BYTE

999 308

The effective speed, in meters per second, of electrons in graphene.

the atoms that form the channel material can randomize electron spins, causing the original signal to fade away before it ever reaches the output side of the device. Finding a channel material that can carry spin signals over transistor-scale distances with few losses—a material that exhibits a long "spin relaxation length"—is thus a key goal in spintronics research.

By that measure, graphene is shaping up to be a winner. The material showed promise when the first spin relaxation length studies were published in 2007. But in the last few months, graphene's lead over alternatives seems to be widening.

In December at the IEEE International Electron Devices Meeting, in San Francisco, Yunfei Gao, a graduate student at Purdue University, in West Lafayette, Ind., presented results showing that graphene could carry spin signals with a decay length of 5 micrometers, the longest distance yet observed for a material at room temperature. Room temperature is key, because it's the starting point for proving practical devices.

The configuration that did the trick was actually a stack of seven layers of graphene. That configuration seemed to cut down on some of the unwanted electrical effects that can crop up due to interactions with the material the graphene must rest on. But devices containing more than seven layers seemed to be at a disadvantage, because less spin signal made it to the layers of the device with the least amount of interaction, Gao says.

The 5-μm result is rivaled by recent findings from a group led by Bart van Wees, a physics professor at the University of Groningen, in the Netherlands. In two recent papers, van Wees's team has shown they can get spin relaxation lengths of 4.5 μm by placing graphene on a relatively uncommon substrate—boron nitride—or by physically suspending the graphene between two terminals over an air gap.

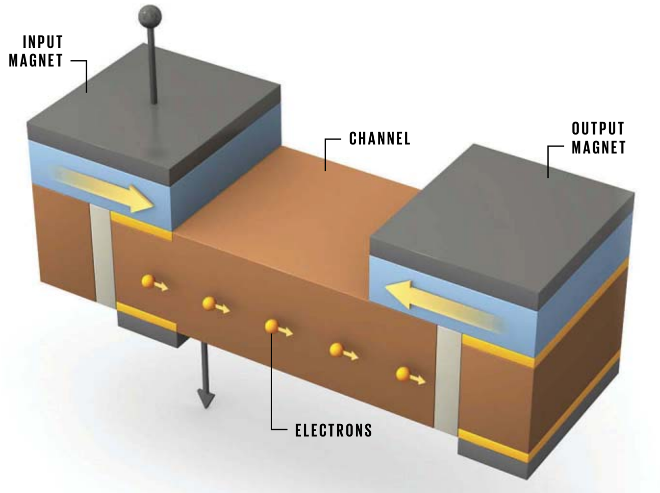
Graphene, says van Wees, is especially promising because electrons zip through it and interact little with the electric fields generated by the materials' relatively low-mass carbon atoms. "I think at room temperature, there are no other materials that have come close," he says, adding that the spin relaxation lengths of both metals and silicon top out at about a micrometer at room temperature.

There is some indication that graphene could do even better than what the Purdue researchers found. In research published in *Nature Physics* in July, a team of U.S. and French scientists measured spin relaxation lengths of 100 μm when graphene was cooled to just a few degrees above absolute zero. Cooling slows atoms, cutting down on some of the processes that can scramble electron spins as the particles move through the material.

Theory predicts that graphene could exhibit a similar relaxation length at room temperature, but so far no one understands exactly why the experimental results fall short. "I think that is the fundamental question at the moment," van Wees says.

It is possible, says Gao's advisor, electrical and computer engineering professor Joerg Appenzeller, that despite graphene's exceptionalism in the transport department, it may not be the best material for future spin devices. He says his team at Purdue is also exploring copper, which is easier to fabricate and to integrate with other components. But he notes that copper doesn't have another key advantage of graphene: the ability to boost the spin signal by increasing the concentration of electrons moving through the material.

"These room-temperature results are promising for future devices," says Kanji Yoh of Hokkaido University, in Japan, an expert in both graphene and spintronics. But he stresses that research into potential materials, as well as for the devices they might eventually be used to build, is at an early stage. "People are still struggling to make a working device, [to figure out] what is the best working structure."
—RACHEL COURTLAND



Spin Transistor

Ideas for spin devices vary. This concept for an all-spin device, proposed in 2010, employs two nanoscale magnets. A voltage applied at the input nanomagnet alters the distribution of electron spins in the channel. If this spin signal is sufficiently strong when it reaches the output nanomagnet, it changes the nanomagnet's magnetization.

NEWS

ILLUSTRATION BY Emily Cooper

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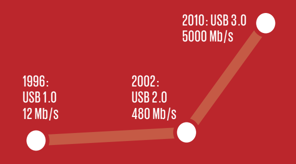
PHOTOGRAPH BY Yoshikazu Tsuno/AFP/Getty Images

BATTLE BOT

KOGORO KURATA, a Japanese designer and artist, shows off the robotic creation he has dubbed Kuratas. The 4-metric-ton, 4-meter-tall machine, built by Suidobashi Heavy Industry, can be piloted from the cockpit—where Kurata is perched—or remotely from an iPhone. The combative robot, whose four wheeled legs allow it to go as fast as 10 kilometers per hour, shoots plastic bottles or BB pellets. Kuratas features a sensor system that locks onto a target before its twin Gatling guns together fire more than 6000 BB pellets per minute. Oddly, the firing frequency is determined by the pilot's smile; the wider the operator smiles, the more rapidly the projectiles fly. This is no one-off project: Its creator says he plans to sell Kuratas units for US $1 million each.

THE BIG PICTURE NEWS

RESOURCES



INTRODUCED IN THE 1990S, USB BECAME THE DE FACTO UNIVERSAL STANDARD FOR CONNECTING PERIPHERALS AT EVER FASTER SPEEDS.

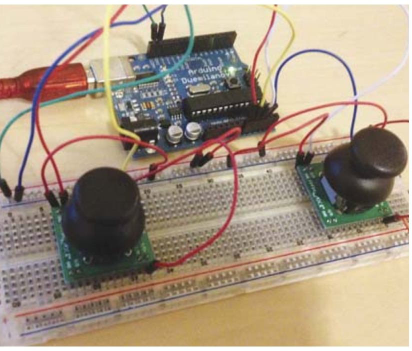
A CUSTOM GAME CONTROLLER

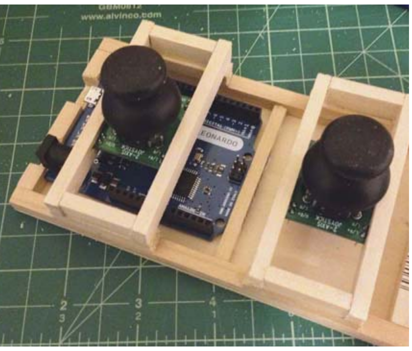
CREATE YOUR OWN USB PERIPHERALS WITH THE ARDUINO LEONARDO

RESOURCES_HANDS ON

I WAS GETTING TIRED OF DINGING THE INTERNATIONAL SPACE Station—not in reality, of course, but in the fantastically detailed (and free) spaceflight simulator *Orbiter*. Unlike most spacecraft games, *Orbiter* tries for as much physical realism as possible, including the need for considerable finesse when docking a spaceship at the ISS's air lock. Unfortunately, the keyboard controls are not particularly intuitive, and most joysticks and other game controllers are designed with airplanes, cars, or avatars in mind, not spacecraft. So I decided to build my own controller. ● The task was made much easier thanks to the release last summer of a new version of the popular Arduino microcontroller. The US $25 Arduino Leonardo can mimic a USB keyboard or mouse, sending keystrokes or mouse movements to a computer in response to circuitry hooked up to the microcontroller. ● While this mimicking is technically possible with other versions of the Arduino, it's a fiddly process that can require additional hardware or ditching the Arduino's native programming software. As I'm a weekend warrior when it comes to programming, the Leonardo's ability to transmit a keystroke with a single line of code was very appealing. ● Once I'd settled on using the Leonardo for the core of my USB controller, I started working on the physical layout. Rather than trying to have a button for each of the 100 or so keyboard commands that *Orbiter* recognizes, I focused on the handful of commands that are most needed during busy maneuvers. ● During docking, in order to align with the air lock, an *Orbiter* pilot must frequently switch between rotating the spacecraft along its roll, pitch, and yaw axes and moving ("translating") the spacecraft in a vertical, horizontal, or sideways direction. ▸

RANDI SILBERMAN KLETT





E-Z USB: Arduino microcontrollers have supporting input/output circuitry built in, so wiring up joysticks was trivial to do in my test setup [top left]. To mimic signals from a USB keyboard, I used an Arduino Leonardo. Wooden supports held the joysticks at the right height [left]. After a minor tweak to the simulator's configuration, I was in command of my virtual spacecraft [above].

A keyboard command switches the spacecraft between rotation and translation modes, which simulates the action of the small thrusters that real spacecraft use for both rotation and translation, but with different firing patterns. Another vital keyboard command stops all spacecraft rotation to prevent the spacecraft from drifting into a confusing multiaxis spin.

With this in mind, I decided on two buttons—one to switch thruster modes and the other to kill any spin—along with small left- and right-hand joysticks.

In rotation mode, the right joystick acts like a traditional airplane joystick—pushing forward pitches the nose down, pushing left rolls the spacecraft to the left, and so on. Meanwhile, moving the other joystick left and right makes the spacecraft yaw back and forth. In translation mode, pushing forward, back, left, and right on the right-hand joystick will accelerate the spacecraft in the matching direction. Moving the left joystick forward and back accelerates the spacecraft up and down.

The joysticks, made by Parallax, cost $5 apiece. These spring-loaded two-axis joysticks are essentially two potentiometers set at right angles to each other. Electrical resistance is proportional to the position of the joystick along each axis.

I also added a switch that turns the Leonardo's ability to send keystrokes on and off (as indicated by an LED on the side of the controller). This switch means I can leave the USB controller plugged in when I'm not using *Orbiter*, without having to worry about, say, knocking against the device and inserting random characters into an e-mail.

Wiring up the components to the Leonardo was easy by design. The Leonardo, like all Arduinos, provides a 5-volt reference voltage and a number of built-in analog-to-digital converters for making exactly the kind of resistance measurements I needed to use the joysticks. The digital input pins can be configured to use internal pull-up resistors to prevent spurious readings, so I could connect the switch and buttons directly to the Leonardo. Digital output pins provide enough current to power my indicator LED, so the only additional component required in the whole system was a current-limiting resistor in series with the LED.

Programming the Leonardo was only slightly more difficult than wiring it up—about 100 lines of code to map the inputs from the joysticks and buttons to outgoing keystrokes, written in a version of C developed for the Arduino.

The trickiest part was constructing the controller's enclosure. As I live in a third-floor apartment, I don't have space for a workshop (or even a dedicated workbench). My equipment is restricted to the small hand tools I occasionally use to build scale models. So a metal enclosure, for example, wasn't really an option.

I settled on basswood. It's commonly used to make architectural models, so beams and strips are available from art supply stores in precut shapes and sizes. Some sawing and gluing of about $5 worth of wood produced an enclosure. The joysticks were held in place by grooves cut into supporting beams. While this arrangement probably isn't robust enough to withstand the kind of button-mashing frenzy a first-person-shooter video game would elicit, it's just fine for the more subtly operated *Orbiter*.

A micro USB cable connects the controller to the computer running *Orbiter*: The computer's USB port provides all the power the controller requires, but I had to install a driver to make Microsoft Windows recognize the Leonardo. When you operate the controller, the existing keyboard and mouse remain active, so *Orbiter*'s full set of commands is available.

I did have to tweak *Orbiter*'s configuration to use the controller. Normally, *Orbiter* assigns the rotation and translation commands to the numeric keypad found on full-size keyboards. However, the Leonardo does not support the ability to distinguish between, say, the *8* on the keypad and the *8* in the row above the letters. Fortunately, *Orbiter* stores its key assignments in an easily edited text file, so a few moments' work mapped the relevant commands onto the keystrokes I had programmed into the Leonardo.

Once that was done, I launched *Orbiter* and was instantly able to control my virtual spacecraft with my new controller. A quick flight around the ISS and a perfect docking confirmed the new ease in spacecraft handling—and the new ease in building custom USB hardware—provided by the Leonardo. —**STEPHEN CASS**

STEPHEN CASS (3)

BLUETOOTH TOOTHBRUSH

THE BEAM BRUSH USES A WIRELESS CONNECTION TO MONITOR DENTAL HYGIENE

DIGITAL DENTAL: The Beam Brush responds to the mouth and wirelessly sends a record of your oral hygiene habits to your smartphone.

Brushing your teeth is one of the few experiences that hasn't varied much over the decades, with the last radical innovation being the invention of the electric toothbrush in the 1950s. So I was thrilled when the Bluetooth-enabled Beam Brush (US $50) arrived, ready for review and promising a breath of fresh air in this most mundane of activities.

The Beam Brush would, I imagined, usher me into a new era of connected oral care and geeky grooming. It senses the mouth's bioelectricity to record each "brushing event," then sends the data to an app (iOS or Android) on a paired smartphone so I could track my stats over time. Toothbrushing may sound like an absurd thing to monitor in detail, but not to the growing market of "quantified selfers" who already wear devices that count the number of steps they take, the calories they burn, and the hours they sleep soundly [see "How I Quantified Myself," *IEEE Spectrum*, September 2012].

To get the best out of the Beam Brush, I found I had to set my phone by the sink. The app's 2-minute timer could then urge me on; my phone vibrated and chirped cheerfully every 30 seconds, displaying the message "Next quadrant!" A music function played the phone's audio files while I brushed. It's easy to imagine that kids might take more interest in their dental hygiene with these encouraging and entertaining features.

Unfortunately, in my twice-daily adult encounters with the brush, I found more difficulties than delights. The nonmotorized Beam Brush is awkward to maneuver: At 57 grams, it weighs slightly less than a regular electric toothbrush, but its tiny, manually operated brush head sits on a bulky handle that has to contain an AA battery and all the electronics. Moreover, as the Beam Brush's lengthy instructions warn, the battery hatch in the back isn't watertight. So I had to hold it at an awkward angle to ensure that foam didn't accidentally dribble down the handle and leak in. My 2-minute brushing sessions went from a task that could speed by in a half-asleep state to what felt like a data-driven eternity.

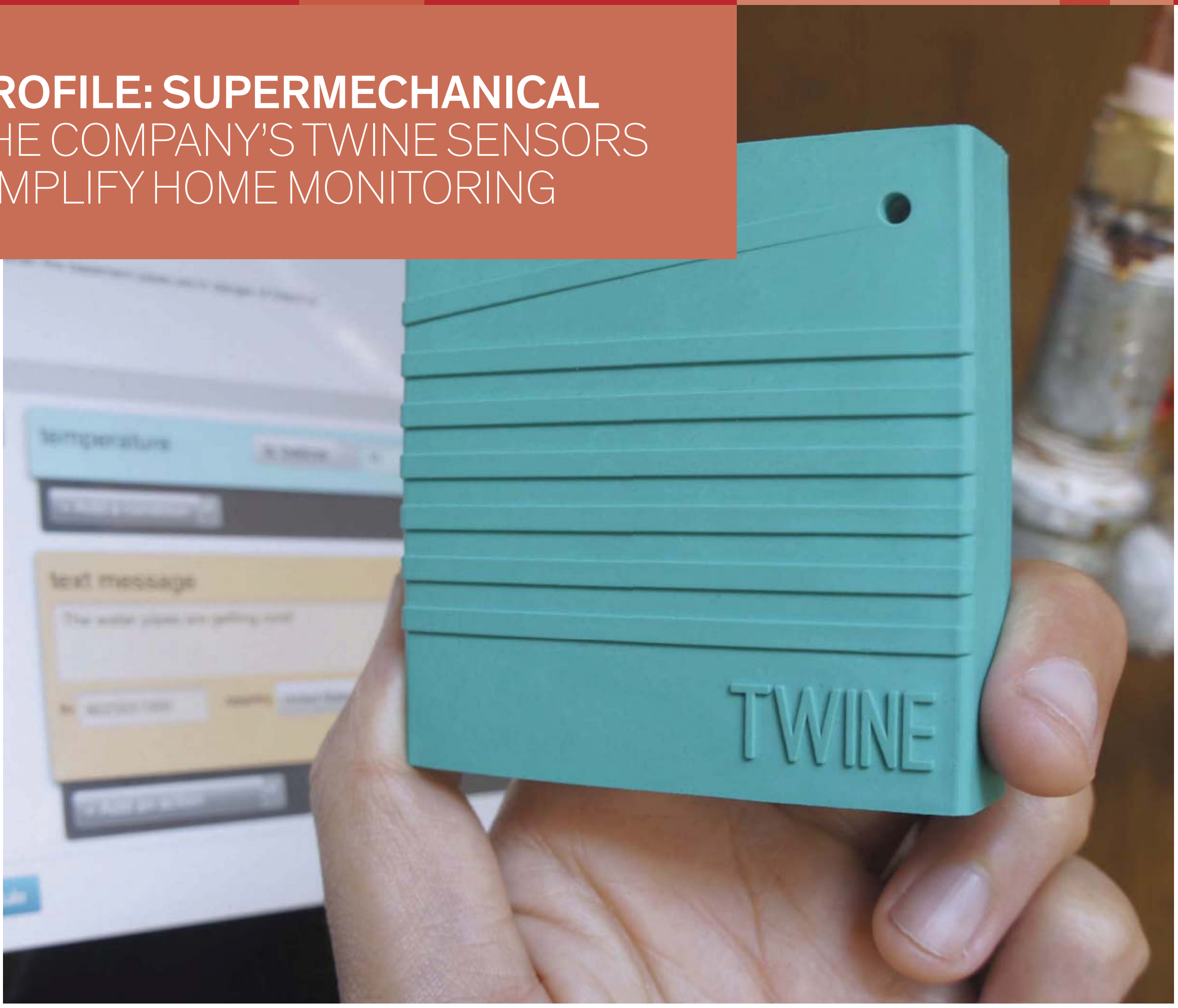
The brush and its app can sync automatically if they're near to each other; otherwise the data is stored on the brush (for up to three weeks) until you are ready to upload it by bringing the phone within range and pressing the brush's one button. The app shows your average brushing duration and, on its calendar, which brushings you've missed.

RANDI SILBERMAN KLETT (2)

But I couldn't get much out of the stats, because I evidently didn't treat the toothbrush with the care it needed when I packed for a vacation. When I unpacked hours later, the brush's LED light was blinking angrily at me and wouldn't stop. The instructions include a list of all the different things the brush's flash patterns could mean, but the difference between a "blip flash," "long flash," and "slow flash" were lost on me. The instructions also point users to an online page that is supposed to provide "visual comparisons of the LED indicator," but I got a "Page not found" error.

Taking out the battery would reboot the brush but also wipe out all my accumulated data. Meanwhile, it blinks on. My toothbrush is trying to tell me something, but I don't know what. High-tech hygiene is considerably more complicated than I expected. —**ELIZA STRICKLAND**

PROFILE: SUPERMECHANICAL
THE COMPANY'S TWINE SENSORS SIMPLIFY HOME MONITORING



SMART SQUARE: Owners can drop battery-powered Twine sensors around their homes to remotely monitor conditions such as temperature and moisture.

THE IDEA OF A SMART HOME HAS BEEN AROUND FOR decades. But until now, you had to be very wealthy—or very nerdy—to have one. A number of companies are aiming to change that, and one of them is Supermechanical, an Austin, Texas–based spin-off from MIT's Media Lab. ● The company's first product is Twine. For US $125, you get a durable rubbery square, 68.5 millimeters on a side, that can text, tweet, or e-mail alerts when specific changes occur in your home. Each Twine block incorporates Wi-Fi, internal temperature and orientation sensors, and a headset-jack-style connector for adding an optional moisture sensor or magnetic switch. (Nerds can still play along, adding their own analog or digital sensors with a breakout board that provides terminals for signals and power.) A block will run for months on two AAA batteries before sending an e-mail to tell you that it's time to change the batteries. ● The alerts you get, and the rules for when you get them, are configured via a companion website hosted by Supermechanical. Simple instructions on how to connect your Twine block to the site, via a Wi-Fi network, are molded into the rubber case. The rules are created by making selections from a set of conditions and actions. For example, a rule might read, "WHEN magnetic switch is open, THEN text 'Pool gate is open!' "

John Kestner and David Carr founded Supermechanical in 2011. Kestner, an industrial designer by trade, approached Carr about commercializing some of their Media Lab projects. After their first product idea—a table that incorporated its own encoded design files etched in aluminum for easy modifications or repairs—failed to generate consumer interest, they went back to the drawing board. "We realized that so many things we wanted to do relied on connectedness," Carr says. "We wanted what became Twine to reach my mom. It needed to not be intimidating. We also wanted it to be rugged.

SUPERMECHANICAL

We chose a headset jack as the connector because it's simple, familiar."

After developing prototypes, the pair launched a Kickstarter campaign in late November 2011. Their goal was US $35 000, which they thought would see them through the three months they estimated it would take to get Twine into production. The campaign garnered almost $560 000 in 40 days. The surplus funds turned out to be the minimum amount they needed, Carr says. It took almost nine months to find reliable manufacturing partners and smooth out the supply chain. Supermechanical started shipping Twines in mid-October. Carr estimates its customers are about 50/50 "nerds to ordinary people."

Supermechanical's competition comes from companies such as ADT, AT&T, Comcast, Lowe's, Verizon, and others that are taking advantage of the proliferation of wireless home networks and smartphones to offer home automation and monitoring services. Market intelligence company ABI Research estimates that in the next five years, 90 million homes worldwide will use such systems. Installation can be complicated, though, and customers are often charged ongoing subscription fees. Supermechanical's founders believe that Twine will appeal to homeowners who want a simple-to-install way to monitor a basement that's prone to occasional flooding without any additional expenses, for example.

Hung LeHong, a Gartner research analyst, says that for Twine to be successful on a consumer level, the price will have to drop below $50 and Supermechanical will need to market it more narrowly. "They have some interesting use cases," he says, "but I think it would be better if they had something more outright, a specific application for it."

For now, in the near term the company is focusing on adding even more functionality to the basic Twine blocks, such as the ability to respond to vibrations, and on making more external sensors available. It also plans to release the specs for sensors so that other companies can make compatible products. "We foresee a Twine ecosystem," Carr says.

—ERIKA JONIETZ

A version of this article appeared online in December.

TOP: MICROSOFT; BOTTOM: JAKOB NIELSEN

RESOURCES_Q&A

Q&A: JAKOB NIELSEN

AN INTERFACE GURU LOOKS AT WINDOWS 8

TILE TAKEOVER: In Microsoft's most radical shake-up of its operating system's user interface since the introduction of Windows, tiles take the place of icons.

USABILITY EXPERT Jakob Nielsen [right] recently put Microsoft Windows 8 through its paces, testing its interface on both desktops and tablets. He identified a number of significant shortcomings and spoke to Steven Cherry about them in December for *IEEE Spectrum*'s podcast series, "Techwise Conversations."

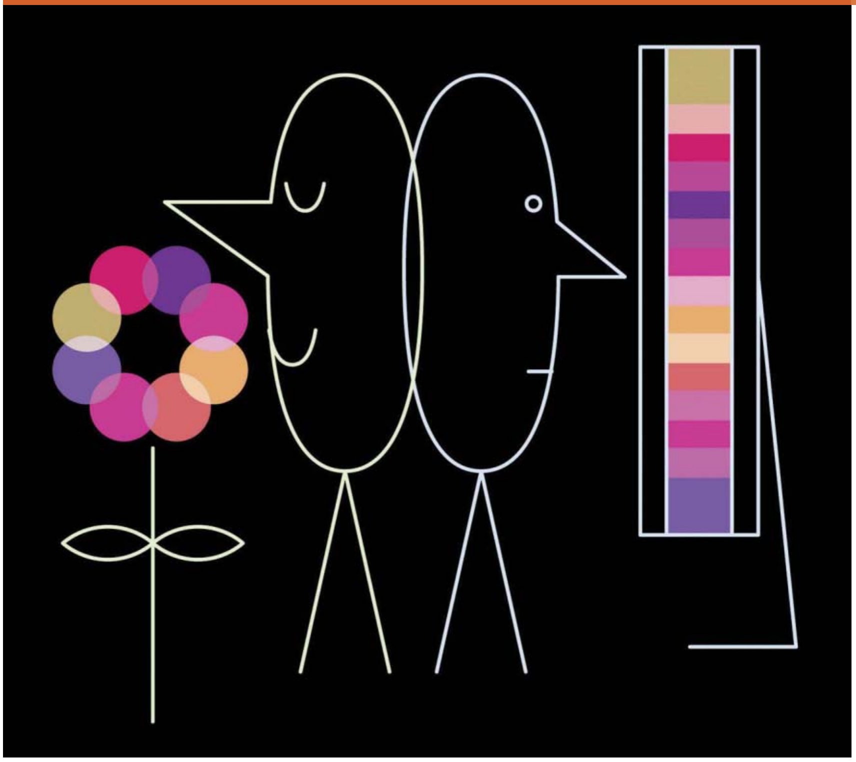
Steven Cherry: One of the key problems you identified in Windows 8 was "reduced power from a single window." What does that mean?
Jakob Nielsen: A single window works perfectly on a phone; you just have that small screen. On a tablet, most of the time a single window is good as well. Scale up to the desktop computer and that falls apart. [Our testers] had a very hard time doing more than one thing—for example, making a list of three possible things to go out to see and then sending that list to a friend. That's the type of thing that Windows computers should be able to do easily.

SC: Another key problem was "reduced discoverability"—what's that?
JN: Discoverability is being able to find out what features are available from the system at any given time, as opposed to having to know them. People are not very good at remembering things, whereas they're much better at noticing things and being reminded. This was the graphical user interface revolution in user interfaces. Things were represented on the screen by icons, by menus, and so forth, as opposed to the older style of the command-line interface. Graphical user interfaces were successfully used by vastly more people than the command-line interface. Now Microsoft has taken a lot of this away by hiding the icons, by hiding the menus, by making it so that you have to remember to put your mouse in the upper right-hand corner to reveal things.

SC: Apple also seems to be slowly merging its iOS mobile and Mac OS X desktop operating systems. Do you think it will fall prey to some of the same problems you found in Windows 8?
JN: Well, if it's a 100 percent [merging], I think it would be a mistake. A desktop computer, a tablet, and a phone—they are three different things. If you try to do things that are identical for two very different platforms, you will not optimize for either one. I think Microsoft tried to optimize for the mobile scenario, and that's why their desktop design falls through so bad. In the case of Apple, who knows what they would do? They might try and do a little bit of a compromise, which would also be bad for both platforms.

These questions and answers have been edited and condensed. To read or listen to the full interview, visit http://spectrum.ieee.org/windows8-1212.


Reduce these Costs
Payment Card Fees
We'll look into it.



BALANCING ACT

[There is a] systematic bias to see the digital and physical as separate; often as a zero-sum tradeoff where time and energy spent on one subtracts from the other. This is digital dualism par excellence. And it is a fallacy. **—social media theorist Nathan Jurgenson**

In the mid-2000s, the phrase on the lips of every cultural maven, pundit, and lifestyle reporter was *work-life balance*, a near-mythical state of equilibrium in which the demands of both a person's job and personal life are equal. At the heart of this popular phrase was the idea that our society was becoming work-obsessed to the point of dysfunction, and only by dialing back the **workweek creep**–the gradual extension of the workweek marked by performing work-related activities during nonwork hours–could we regain equipoise. ● Well, *that* didn't work. Those of us lucky enough to have jobs are working more than ever, and leisure is increasingly giving way to **weisure**–free time spent doing work or work-related tasks. So our cultural Cassandras had to come up with something else to demonize, and they've settled upon technology itself. They say that our former work obsession has morphed into a technology obsession in which we prefer fiddling with shiny gadgets over relating to real people. The new cri de coeur is for **tech-life balance**. We must, the battle cry goes, learn to use technology in ways that don't interfere with or reduce the quality of our personal lives or relationships. ● Hence the proliferation of **disconnect porn**–articles and features that tell us to turn off, tune out, and drop in on people in the real world. We hear about **black-hole resorts**, which block all incoming and outgoing Internet signals, part of a larger category of technology-free traveling called **disappearance tourism**. We're told to increase our doses of **NST** (non-screen time) and to spend more time living *IRL* (in real life). This demonization of the online experience and insistence that the overconnected unplug and revel in the real has been dubbed the **IRL fetish**.

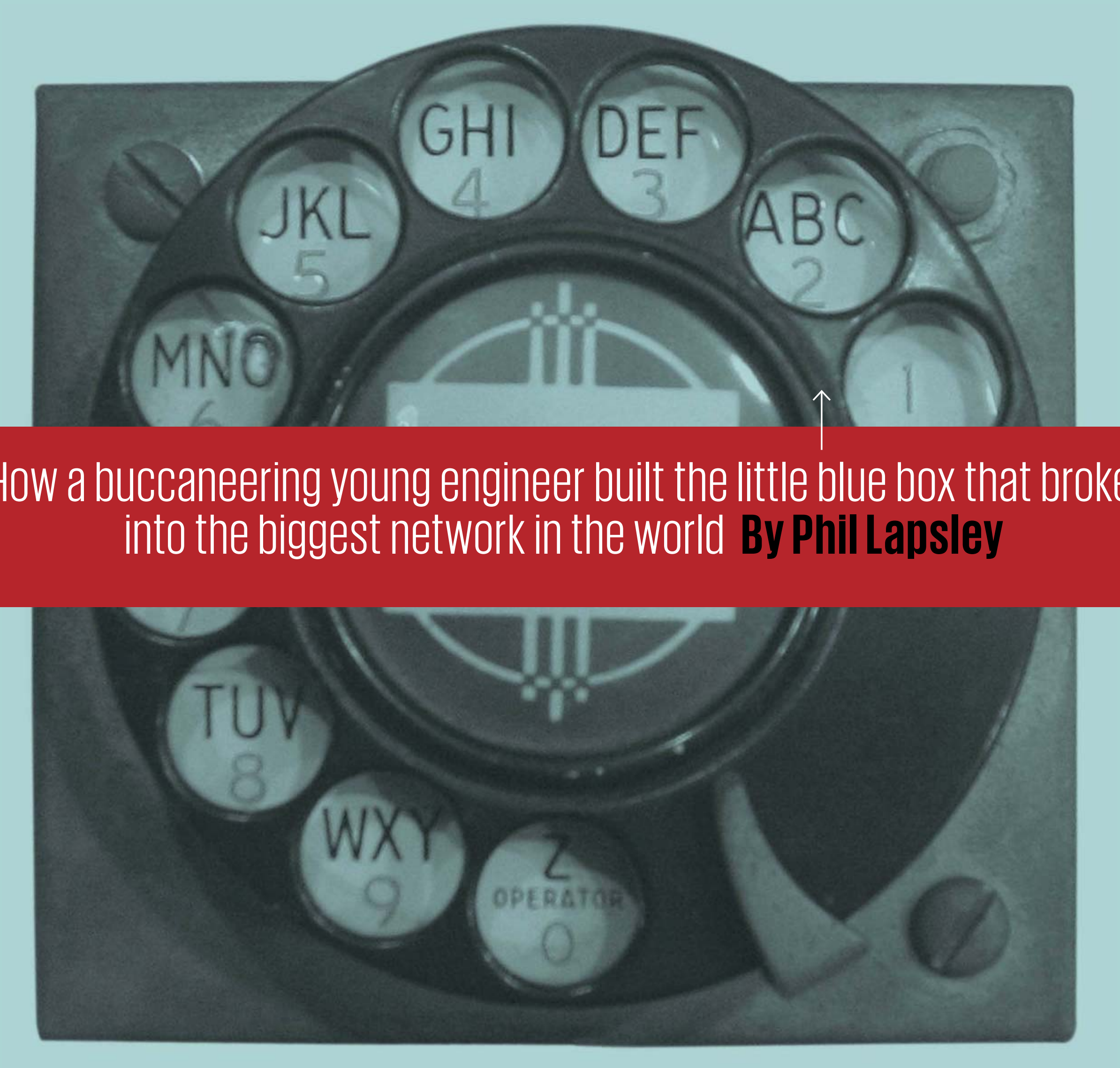
But some people reject the very idea of tech-life balance because they believe we can no longer separate "tech" from "life." The sociologist Nathan Jurgenson calls this belief **digital dualism** and describes it as viewing the physical as fully "real" and the online as merely "virtual" and compares these **digital dualists** to the Cartesian philosophers who believed that the mind was separate from the body.

But according to Jurgenson and others, cyberspace (a term they reject because of its inherent dualism) is real not only because it is imbued with the thoughts, ideas, and feelings of a couple of billion people but also because it has off-line effects. Witness, for example, the often-horrific consequences of **cyberbullying**, such as the recent suicide of teen Amanda Todd. Moreover, the real world isn't separate from what happens online because we now think about online processes even when we're not connected. When a particularly tasty-looking meal arrives we think about posting a picture of it to Facebook; when we watch a presidential debate, we reach for the phone to tweet our reactions to it; when we're on a trip, we are already deciding which images and thoughts we will post to our vacation Tumblr.

But surely the fetishization of IRL experiences derives not from dualistic thinking but from a fundamental asymmetry in how the online and the off-line are enmeshed. That is, in the same way that the mind is fully created by and dependent upon physical structures such as neurons and synapses and is animated by the release of neurotransmitters and other physical processes, so too is cyberspace fully created by and dependent on fiber-optic lines and routers and is animated by social processes such as the posting of photos. On the other hand, the colonization of the physical by the virtual is only partial. Yes, we often think about **Facebooking** or tweeting or **Tumblring** a current experience, but often we're just engaged in the business of life with no thought to the online realm. As long as that remains true, what need is there for tech-life balance? However, if your first thought with any new experience is deciding whether it's **tweetable** or **Facebookable**, then we should probably talk. ■

ILLUSTRATION BY Greg Mably


Phreaking Out Ma Bell



How a buccaneering young engineer built the little blue box that broke into the biggest network in the world **By Phil Lapsley**

LEFT: AT&T; RIGHT: PHIL LAPSLEY

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Ralph Barclay was walking through the engineering library at Washington State University, just minding his own business, when it called out to him. He couldn't say why, it just did. ¶ It was a booklet, about 18 by 23 centimeters and maybe a centimeter thick, on display in the library's new periodicals section. Its pale blue cover proclaimed it to be the November 1960 issue of something called *The Bell System Technical Journal*. It had been out for less than a week.

Barclay looked at the table of contents printed on its cover. Most of the articles could put even the hardest of hard-core geeks to sleep at 20 paces: "Magnetic Latching Relays Using Glass Sealed Contacts," "Molecular Structure in Crystal Aggregates of Linear Polyethylene," or the ever popular "Ionic Radii, Spin-Orbit Coupling, and the Geometrical Stability of Inorganic Complexes."

But one title caught his eye: "Signaling Systems for Control of Telephone Switching." He flipped to the article and started skimming. Minutes passed. His original purpose for coming to the library shelved for the moment, he sat down and began to read in earnest.

Barclay was just 18. Athletic and of medium build, with brown hair and blue eyes, Barclay had started his first year at Washington State's Pullman campus, about 50 miles [80 kilometers] south of Spokane, just a couple of months earlier. "I was living in the dorm," he remembers, "and a lot of people in the dorm are looking for ways to make cheap phone calls home to their girlfriends and parents and suchlike." One of the guys in the dorm had "somehow," he says, acquired his own personal pay telephone. And although students weren't allowed to have telephones installed in their rooms, for some reason the dorm rooms still had telephone lines in them.

Barclay's dorm had quite a few engineers in it–and engineers, Barclay allows, are a problem. The engineers soon determined that somebody had left the door unlocked to the building's telephone closet, the little room where all the telephone wires come from. In the dark of night an operation was mounted. Certain wires were cross-connected. Et voilà: A pay telephone line from somewhere on campus ended up connected to the personal pay phone in Barclay's dorm. Barclay and the other kids in the dorm could now make telephone calls by depositing money in the pay phone, just like usual. The difference was this: The owner of the pay phone–apparently not a business major–was a nice guy and returned the caller's money after each call.

Maybe it was this pay phone hack that caused Bells to ring in Barclay's brain when he spotted the article in the *Bell System Technical Journal*. The article laid bare the technical inner workings of AT&T's long-distance telephone network with clarity, completeness, and detail. It was all there: how the long-distance switching machines sang to each other with single-frequency (SF) and multifrequency (MF) tones, how 2600 hertz was used to indicate whether a telephone had answered, what the frequencies were of the tones that made up the MF digits, how overseas calls were made–it even included simplified schematic diagrams for the electrical circuits necessary to generate the tones used to control the network. Nothing was hidden.

By the time Barclay finished reading it, the vulnerability in AT&T's network had crystallized in his mind: "I thought, this is a better way than using a pay phone...this is a way to get around all that other stuff and do it directly."

"It," of course, was making free calls.

The ability to absorb 64 pages of dry, technical mumbo jumbo and spot the vulnerability is a rare one. The engineers from Bell Labs who designed the system and wrote the article didn't see it. Thousands of engineers in the future would read that article and not see it. But 18-year-old Ralph Barclay did. The funny thing about it is, once the hole is explained to you, it's obvious. But until it's explained to you, most people would never think of it. Certain people have minds that are tuned in a particular way to see things like that. Ralph Barclay was one of those people.

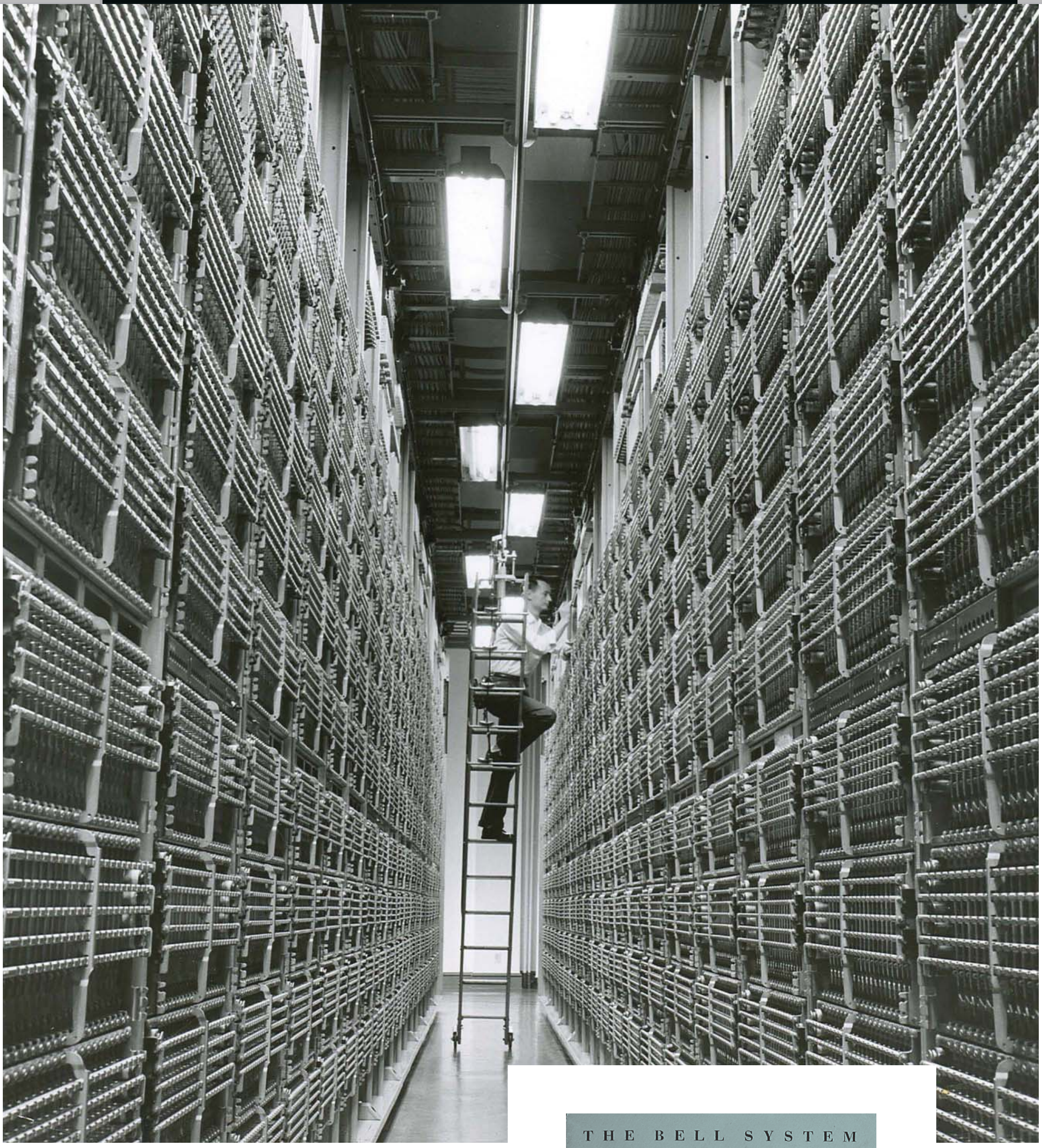
To understand Barclay's insight we have to think back to the things that made up AT&T's automated long-distance network–things like the spectacularly named #4A crossbar switching system that was the brains of the long-distance telephone network, and how the machines talked to each other by speaking in tones. Because that's what the *Bell System Technical Journal* described and that's where Ralph Barclay spotted the flaw. Here's what he came up with:

Say you're in Seattle and, as always, you want to call your friend Bill in Denver. With Barclay's hack, your first step is to pick up the phone and dial directory assistance in any city–let's say New York just for fun: 212-555-1212. Unlike today, calls to directory assistance were free back then.

Seattle and New York are both big cities and have direct trunk lines between them. On a given long-distance trunk line between Seattle and New York, the switching machine in Seattle sends a 2600-Hz tone–7th octave E–to New York to indicate that the line is idle. New York sends the same tone back to Seattle to indicate that the line is not in use on its end either. Remember how in a flight of fancy an AT&T manager described the switching machines as "singing" to one another? This is the boring part of that song: You can think of it as the machines monotonously whistling this single note back and forth. It's almost like they're keeping each other company, reassuring each other that they're both still there.

As you dial the last digit of the number for New York directory assistance, the fancy switching machines and their signaling sys-

This article is an excerpt from *Exploding the Phone: The Untold Story of the Teenagers and Outlaws Who Hacked Ma Bell* © 2013 by Philip D. Lapsley; reprinted with the permission of the publisher, Grove/Atlantic.



tems spring to life to get your call through. Seattle finds an idle trunk to New York and stops whistling 2600 Hz on it. New York hears the trunk go silent, indicating that Seattle wants to make a call. New York sends back a "wink" signal—really just a moment of silence, no 2600-Hz tone, for about a quarter of a second. This wink tells Seattle that New York is ready and waiting for Seattle to tell it a phone number to call. Using either the SF or MF signaling language, Seattle sends New York the digits 555-1212. In SF-speak, this is a series of beeps of 2600 Hz. In MF-speak, it consists of nine quick little pairs of tones that sound like brief musical notes: KP, 555 1212, and ST. The special signal called KP ("keypulse") at the beginning tells New York to get ready, and the final note, ST ("start"), tells New York that it now has all the digits and it can start dialing.

THE BELL SYSTEM

Technical Journal

DEVOTED TO THE SCIENTIFIC AND ENGINEERING ASPECTS OF ELECTRICAL COMMUNICATION

VOLUME XXXIX — NOVEMBER 1960 — NUMBER 6

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A lobe of the "brain" of the Bell System's #4A toll crossbar switching system, circa 1957, is shown above. It was the first system to allow people to dial long-distance calls themselves. A description of its signaling in this technical journal [left] gave hackers a way in.

TOP: AT&T ARCHIVES AND HISTORY CENTER; BOTTOM: PHIL LAPSLEY

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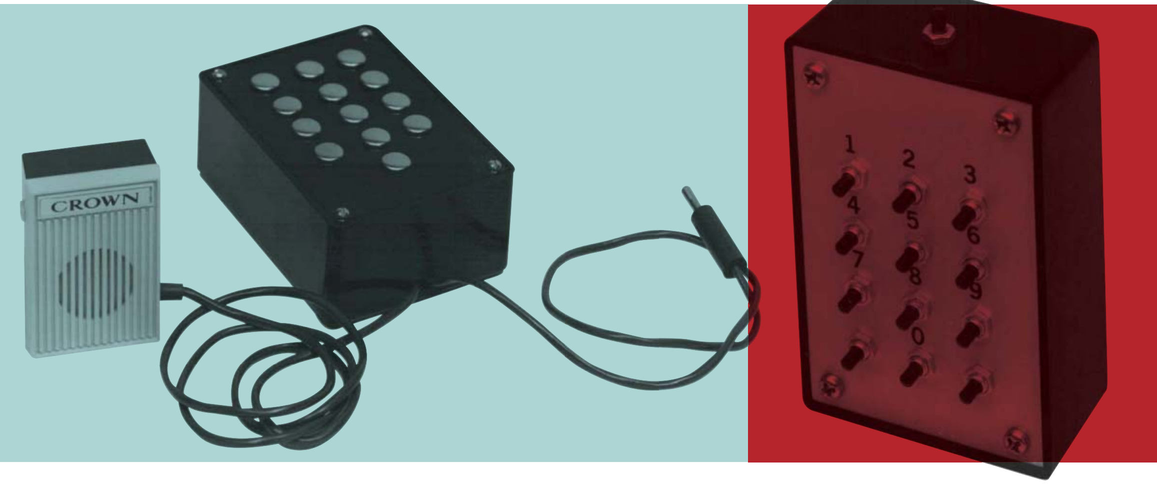
CALLING MA BELL... COLLECT!

This assortment of blue boxes from the 1970s mirrors standard telephone design, which underwent a transition from dials to touch-tone buttons.



Now that New York knows the number you want to call, it makes the local connection and the directory assistance operator's telephone starts to ring. Up until now everything that has happened has been perfectly normal, just like Ma Bell intended. But now you, using Barclay's hack, insert yourself into the process. Before the operator can answer, you—naughty you—hold a speaker up to your phone's mouthpiece and play your *own* 2600-Hz tone down the line for a second.

It is loud and pure, and it sounds like this: "Bleeeeeeep."

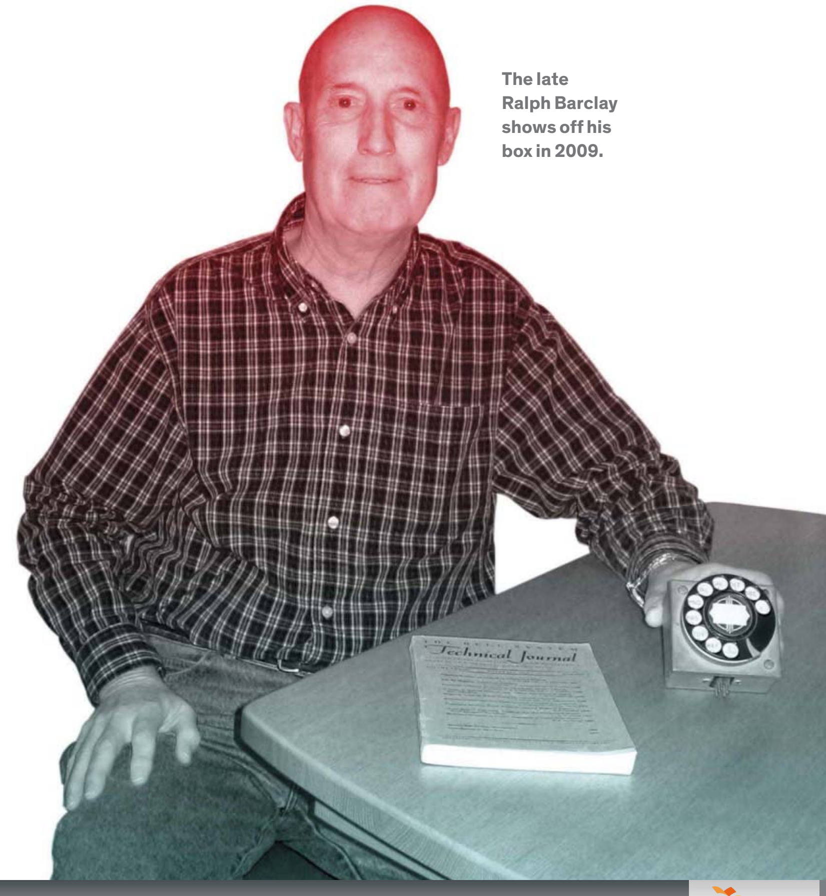
Seattle isn't paying any attention to this, but the switching machine in New York sure is. New York hears your 2600-Hz tone loud and clear and thinks that the Seattle switching machine sent it. And since this tone indicates the trunk line is idle, New York figures that Seattle is done using that trunk line, probably because you hung up. New York disconnects the call to the directory assistance operator—maybe before she's even answered.

But now you stop sending your tone. When you stop sending 2600 Hz, the long-distance switching equipment in New York City now thinks that Seattle wants to make another call. Just like before, New York sends a wink back to Seattle to say that it's ready for a new call. Due to the nature of the circuitry involved, the wink has a bright, metallic, ringing quality to it. It sounds like this: "Kerchink!"

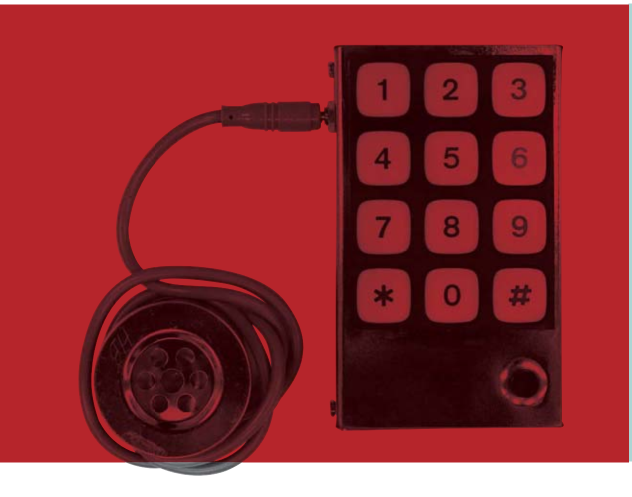
That noise tells you that you have just fooled New York into thinking that a new long-distance call is coming in. Once again, the switching machine in New York is waiting for Seattle to tell it digits to dial. But Seattle isn't going to tell it anything, because Seattle is blissfully unaware of everything that has just transpired. The only thing Seattle knows is that you haven't hung up—you're still on the line, after all—and Seattle believes you can only make one call every time you pick up the phone. As far as Seattle is concerned, you're still talking to New York directory assistance.

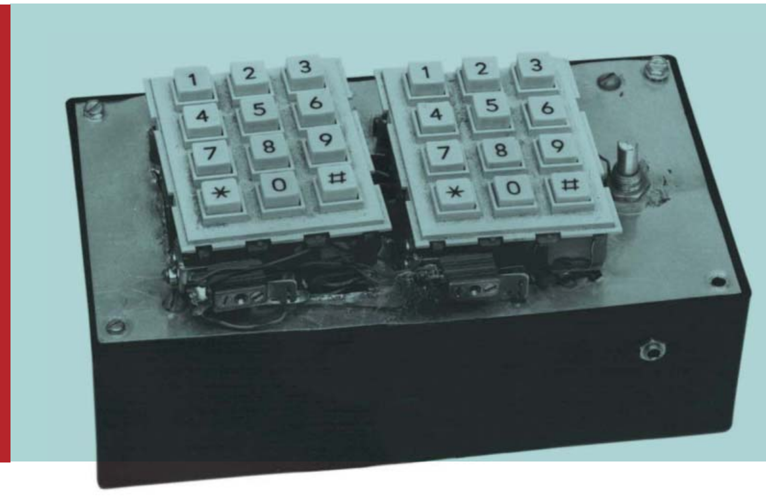
You, on the other hand, know better: You possess guilty knowledge. Using a simple little electronic circuit, you can generate the same pairs of tones that Ma Bell's telephone switches use to serenade each other. Once again holding up a speaker to your phone, you play the tones needed to send New York the digits KP + 303 722 7209 + ST—that is, the number of your friend Bill in Denver. Now of course, area code 303 isn't in New York City, but that's okay: The telephone switch in New York is a brainy #4A and knows how to route calls from one place to another—after all, Bell Labs worked hard to give it the brains to be able to do that. New York happily finds a trunk line to Denver and puts your call through, sending out tones on your behalf to instruct Denver on what number to dial. Moments later, Bill's phone starts to ring.

Congratulations: You've just hijacked a phone call to directory assistance in New York and rerouted it to Bill in Denver. But



The late Ralph Barclay shows off his box in 2009.





that's only half the trick. The other half is this: Your phone call to Denver is free. Why? Because Seattle is responsible for the billing of your phone call. As far as Seattle is concerned, you're still connected to directory assistance in New York—and directory assistance is a free call.

Barclay really had three insights when he read that article in the *Bell System Technical Journal*. The first was that sending a 2600-Hz tone down the line resets the remote switch but doesn't affect the local switch. The second was that you could then reroute a phone call from the remote switch to wherever you want. And the third was that the local switch is in charge of billing, so it continues to bill you for whatever call it thinks you originally made. With those three insights, he now owned Ma Bell's network.

A few weeks after reading the *Bell System Technical Journal* article, Barclay made the 3-hour drive west to his hometown of Soap Lake, Wash., population 1200. Home may be where the heart is, but for Barclay, home was also where his workbench, soldering iron, and electronic components were. "I was an electronic tinkerer for years and years and years," he says. A curious one, too: His older sister remembers Barclay plugging a bobby pin into an electrical outlet when he was 4. His father, a truck driver in rural Washington, used to bring him broken TVs to fiddle with, and his bedroom was littered with electrical equipment, telephones, and radios. Barclay landed his first job—repairing broken radios—when he was in the fifth grade.

Barclay's first box took a weekend to build. It was a simple affair, housed in an unpainted metal enclosure about 10 cm on a side and perhaps 5 cm deep. Inside was a 9-volt battery and a single transistor oscillator circuit. On the outside the box sported a surplus rotary telephone dial and a red push button. The red button would allow Barclay to disconnect a call in progress—to "seize a trunk," in both telephone company and "phone phreak" parlance—by producing a 2600-Hz tone for as long as he held it down. When spun, the rotary dial would make short blips of 2600 Hz. If Barclay dialed the digit 6, for example, it made six short beeps. In other words, it would allow him to send digits using the older SF language.

"I was surprised!" Barclay recalls. "It worked fine the first time!"

CLOCKWISE FROM TOP LEFT: ED TURNLEY (3); PHIL LAPSLEY

As it happens, it also worked best the first time. Barclay quickly ran into a problem: By 1960, fewer and fewer trunk lines used SF signaling. In its push for progress and dialing speed, the Bell System was well on its way to converting most long-distance trunks to multifrequency signaling. And those trunks didn't respond to Barclay's single-frequency beeps. The red button still worked—he could disconnect a call in progress and hear the "kerchink" come back from the remote end—but dialing was often a problem. "It worked sometimes, not consistently," he says—maybe one in four calls.

"That's when I discovered that I needed multifrequency," he says—that is, he needed to generate pairs of tones for each digit as well as for the special "keypulse" and "start" signals. Barclay started work on his multifrequency box over Christmas break. It was more complicated than the first box, what with more transistor oscillators and associated wiring and all that, so it took a bit longer to build.

Barclay added a rotary dial for making blips of 2600 Hz, but that was really just for old times' sake: The real way you'd dial with it, the modern way, was with push buttons. Touch-tone phones weren't a commercial reality yet, so Barclay had to come up with his own telephone keypad. He ended up using keys from an old mechanical Burroughs adding machine. Each key was fastened to a push-button switch mounted underneath it. There were 12 keys in all: Ten for the digits 0 through 9, one for the KP signal that needed to be sent before the digits, and one for the ST signal that needed to be sent after the digits.

Post your comments online at http://spectrum.ieee.org/phonephreaking0213

He had it finished by Easter and it worked like a charm. He and his device became popular among a small circle of friends in his dorm, where he made calls home for them. But mostly, he says, he used it to play with the telephone network, "to see where we could call." As Barclay recalls it, "there were very, very few calls I made that were actual phone calls"—that is, calls in which he called somebody he knew and wanted to talk to.

His new device was housed in a metal box, 30 by 17 by 7 cm and happened to be painted a lovely shade of blue. Barclay did not know it at the time, but the color of his device's enclosure would eventually become synonymous with the device itself: The blue box had just been born. ■

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WHEN WAS THE LAST TIME you saw an engineer portrayed glamorously in a film—or, for that matter, in any form of popular culture? Right. Let's face it: The unflattering stereotypes persist, and they're tired. They're also out of touch with reality. Just consider the five engineers we profile here. • Simon Hauger [center], for example, trained as an electrical engineer but became a math instructor at an inner-city school that most other newly minted teachers would have written off. Now he's bringing hands-on learning to a new level. Geoff Martin, at the other extreme, studied music, not engineering. But technology

DREAM JOBS » 2013

has always been a keen interest, and now this longtime member of the Audio Engineering Society spends his workdays creating some of the world's most innovative audio gear. The three others in our group have traveled paths that are no less fascinating. • So don't buy into the stereotypes. The reality is that engineers emerge from varied backgrounds and do a wide range of vital and interesting work. Now all we need is for one of them to make a movie about it. ▸▸

LEARNING BY DOING: Simon Hauger inspires high school students at the Sustainability Workshop.

PHOTOGRAPH BY Bill Cramer/Wonderful Machine

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[EDUCATION]

DREAM JOBS » 2013

Hands-on Teacher

SIMON HAUGER HELPS INNER-CITY HIGH SCHOOLERS BUILD CARS AND START BUSINESSES

THE DARK GRAY JEEP WRANGLER, modified to run off batteries instead of gasoline, wowed the judges at the Pennsylvania state science fair. The year was 1999, and electric vehicles of any kind were still a novelty in the United States. But then the judges took a closer look at the high school students who had converted the Jeep–mostly black teenagers from an inner-city Philadelphia neighborhood–and decided they couldn't possibly have done the work themselves. So the judges passed the e-Jeep by, awarding their highest rankings to lesser projects.

Simon Hauger, an electrical engineer turned math teacher, was mentoring the students, and he protested–loudly–that the judges should at least have questioned his team before drawing conclusions. The event organizers' response? The youngsters needed to learn that sometimes life just isn't fair. But these kids had already received more than their share of hard lessons. "One kid's father was dying of AIDS," says Hauger, the outrage he felt at the time still audible in his voice. "The conversation turned ugly, and they told me to leave because I started to lose it."

To avoid any further such incidents, Hauger steered his students away from science fairs and toward a more objective competition: the American Tour de Sol, an annual road rally for solar, electric, hybrid, and alternative-fuel vehicles. In their third year of competing, Hauger's students achieved first place in the all-electric category and second in hybrids, beating many college teams. They went on to take the tour's top honors with a head-turning hybrid-electric sports car in 2005 and also in 2006, the competition's final year.

IN 2007, Hauger got wind of a new and even bigger event, the US $10 million Automotive X Prize. Intended to spur the commercialization of superefficient vehicles, this global competition was aimed at industry, requiring entrants to submit business plans and to design production-ready prototypes. So Hauger explained to his students that the X Prize wasn't for them. "Like most people, when you're told you can't do something, you really want to do it more," he says. At his students' urging, Hauger registered his team for the competition–the only high school group to do so.

Soon, the West Philly X Prize team began to garner attention in local and even national press, and the school's automotive shop started getting some famous visitors: a Pennsylvania congressman, a NASA rocket scientist, even rapper Wyclef Jean, who is "an off-the-charts car buff," according to Hauger. "I keep waiting to wake up from this X Prize Dream I seem to be trapped in," he wrote at the time on his blog.

But the dream continued. Against all odds, they ended up as one of 30 teams, from a field of 111, to make it to the on-track trials. The West Philly team entered two cars that they had hybridized: a Ford Focus and a kit car called the GTM Supercar, from Factory Five of Wareham, Mass. Neither was quite able to achieve the 67-mile-per-gallon (3.5-liters-per-100-kilometer) fuel efficiency needed to get past the second round of the trials, held in the spring of 2010 at the Michigan International Speedway. But it almost didn't matter. Hauger's students were considered heroes in Philadelphia–and in Washington, D.C.

President Obama invited them to the White House and noted their achievement in a speech introducing an educational initiative: "They didn't have a lot of money; they didn't have the best equipment; they certainly didn't have every advantage in life. What they had was a program that challenged them to solve problems and to work together, to learn and build and create."

HAUGER GREW UP IN PHILADELPHIA, where he went on to study electrical engineering at Drexel University. There he entered the co-op program, which combines academic study with employment in local industry. Hauger says he enjoyed the analog-design work he did for General Electric, but after looking at the older engineers in the cubicles around him, he "had an epiphany"–an apt choice of words given that his decision to switch gears and go into teaching was motivated, at least in part, by religious convictions.

After earning a bachelor's degree in electrical engineering in 1993, he immediately enrolled in Drexel's School of Education, where he obtained a master's degree and a teaching certification. He then applied to the Philadelphia school district, although any of the nearby suburban schools would have paid much better. "Growing up in the city, I experienced a lot of the injustices we have in society firsthand–even though

I'm not a minority," he says. "So I didn't want to just be a math and science teacher; I wanted to be an *urban* math and science teacher." So he went to work in West Philly.

He soon realized, though, that the educational system he had become part of was badly broken. "You see kids dropping out, and you know what the consequences are. It is incredibly difficult to make sense of that and continue in the profession," he says.

So 15 years ago, he took matters into his own hands, by helping kids assemble electric and hybrid cars after hours in West Philadelphia High's automotive shop. He wasn't paid for these after-school activities; indeed, he often spent his own money on equipment and supplies. But seeing his students become increasingly engaged with school through this informal program, he knew his investment was paying dividends.

"Teaching doesn't have to look like desks in rows in classrooms," he says. Educators work that way only because "we're forced into the most-efficient delivery system." In underserved urban districts like West Philadelphia, he adds, that system breaks down. "The results are horrific–50 percent of kids are dropping out."

Simon Hauger

IEEE Member **AGE** 42 **WHAT HE DOES** Teaches high school seniors. **FOR WHOM** The Sustainability Workshop **WHERE HE DOES IT** Philadelphia Naval Shipyard **FUN FACTOR** Drives a superfast biodiesel Jetta modified by his students.

PHOTOGRAPH BY Bill Cramer/Wonderful Machine

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DREAM JOBS » 2013

Now Hauger is taking this hands-on approach to a new level—he's building his dream school.

HAUGER AND A SMALL GROUP of like-minded teachers hope to harness the power of project-based learning in a school they are designing from scratch, called the Sustainability Workshop. They are now fleshing out their ideas in a two-year pilot program that provides an alternative education for 30 Philadelphia-area high school seniors. It's housed in a small Victorian-era building in the city's old naval yard, now a hub of energy-efficiency research and entrepreneurship.

Hauger has brought his own formidable problem-solving skills to bear in this endeavor. "He thinks about how to engineer a school," says Aiden Downey, a cofounder of the Sustainability Workshop and a professor of educational studies at Emory University. "When people say, 'school,' they think, 'Sit down, shut up, start writing, and take a test.' This is so different."

"Problem-based and project-based education is…messier," Hauger admits. "It's not as efficient. There's no way you're going to cover every topic in Algebra II in one year. But where it excels is engagement." He and his colleagues are deliberately incorporating into the curriculum things like communication skills and building students' self-awareness of their personal strengths and weaknesses. "None of that's done in [traditional] high school," he says.

Hauger and his colleagues know they'll need to assess how they're doing as they work to turn the workshop into a full-fledged four-year high school. "Education needs to be held accountable. The question is, to what?" says Hauger. The standardized tests that traditional schools rely on cater to "the lowest common denominator," he says. "Schools all over the country are test-prep machines." The Sustainability Workshop is built on a different premise—that what students will face in life are imperfectly structured problems and that success is best measured with something other than penciled-in bubbles.

Here's how that premise plays out: To learn how to tackle authentic challenges, workshop students pursue projects that attempt to solve true problems facing society. Last year, for instance, some of them worked to start a business that would provide otherwise-pricey LED bulbs to customers for free; revenues would come from the energy savings that accrue over time. In the process of fleshing out the business plan, Hauger says, one student went from being too shy to address her own classmates to presenting the idea to Philadelphia's mayor, U.S. congressmen, and Google executives. That, says Hauger, was a far larger achievement than getting all the answers right on a multiple-choice exam.

"If standardized testing was guaranteeing future success, we'd all throw our hats into that ring. But it's not," says Hauger. "We'd better come up with a better solution." The Sustainability Workshop provides one promising model. And even if it doesn't prove the best one, thoughtful teachers need to acknowledge the failings of the current paradigm and explore inspired alternatives, he says. "Let's do it and stop making excuses."
—DAVID SCHNEIDER

[SPORTS]

Augmented-Reality Pioneer

LI CHEN TURNS ORDINARY SPORTS GOGGLES INTO DIGITAL DASHBOARDS

HANGING IN THE LOBBY at Recon Instruments is a framed postcard from Mischo Erban, who last year clocked the fastest standing longboard run ever: 129.94 kilometers per hour—over 80 miles per hour.

Recon doesn't typically receive thank-you notes from extreme skateboarders like Erban—the company primarily sells its high-tech goggles to skiers. The eyewear projects real-time data (such as speed, location, jump airtime, and text messages) onto a microdisplay, providing the person wearing them with a virtual dashboard that appears to hover 1.5 meters in front of the lenses. The Vancouver, B.C., Canada, start-up pioneered these augmented-reality goggles years before Google debuted its much-touted head-mounted display, Google Glass.

Erban didn't know it, but he owed the bulk of his gratitude to Li Chen, the humble and meticulous engineer who was the company's first employee. Although Chen won't readily admit it, he almost single-handedly built and programmed Recon's original prototype, which eventually evolved into Erban's helmet-mounted display. "We joke that Li wrote the entire operating system for the first product," says Alex Dunfield, one of Chen's coworkers. "We called it LiX."

CHEN NEVER IMAGINED his job would be the envy of sports gearheads. He grew up in the mountain city of Shiyan, China. The area, sometimes known as the "Detroit of China," serves as the country's center for automobile manufacturing. Chen never became interested in cars, but he was mechanically minded.

Whenever he got a new toy or gizmo as a boy, he would immediately take it apart and try to reassemble it. He could easily see how the gears and levers of his mechanized playthings operated. But each time he came across a control chip, he wondered: "What the heck is that black magic square?"

His curiosity drove him to study electronics engineering at Wuhan University. When he

Li Chen

IEEE Member **AGE** 30 **WHAT HE DOES** Augments reality for sports enthusiasts. **FOR WHOM** Recon Instruments **WHERE HE DOES IT** Vancouver, B.C., Canada **FUN FACTOR** Gets to say, "I did it before Google!"

graduated in 2005, he realized he still lacked an intimate knowledge of how semiconductors work, and so he applied to master's programs in the United States and Canada. He ended up joining the nanoelectronics group at the University of British Columbia, where he investigated the performance of miniature transistors fashioned from carbon nanotubes.

Then one day in 2008, during his last semester, a friend introduced him to Hamid Abdollahi, a fellow graduate student who, with three recent UBC alums, had just formed a company to make smart sports goggles. The four founders hatched the idea during a class they took together that teamed business and engineering students. One member of the group, Dan Eisenhardt, who had been a competitive swimmer in Denmark, proposed making goggles that could display real-time training data, such as heart rate, lap time, and stroke count, right before a swimmer's eyes.

To the team's disappointment, Abdollahi soon discovered that someone else already owned a patent for swimming goggles with a head-up display. So Recon decided it would instead build electronically augmented ski goggles, then move on to motorcycle helmets and bicycling glasses. As the nascent company's chief technology officer, Abdollahi first had to hire an engineer who could help him build a prototype. He began by interviewing master's students at UBC and took to Chen instantly. "He was the smartest kid I met," Abdollahi says.

For a workspace, Abdollahi rented a small office at UBC. The room, not much larger than a walk-in closet, was stuffed with dusty chairs and a couple of broken desks. He and Chen hauled out those discards and replaced them with two new tables, a printer, a fax machine, and a potted plant. Then they got to work.

For their first system, they connected a gyroscope, a compass, and a GPS receiver to a microprocessor and a tiny display. Chen wrote the code that pulled data from the sensors and showed the results on the small screen. He tested the system by racing around campus and watching the display update. The equipment was so big he had to carry it in a backpack, but it proved that Eisenhardt's idea could work.

The next big challenge was to shrink all those electronics into a lightweight package that could fit into a plastic lens frame.

The job was too big for a two-man tech team, though. So Abdollahi rented a second office and hired more engineers. Soon their tiny rooms were packed so tightly that Chen could barely squeeze his laptop onto a corner of his shared worktable. "It was okay with me," he jokes. "I came from a crowded country."

HE WOULDN'T BE CRAMPED for long. By the time Recon released its first product in November 2010, it had moved into a spacious warehouse in downtown Vancouver. Chen now finds himself with plenty of elbow room during the workday, in an airy office surrounded by coffee shops and art galleries. Indeed, Recon's headquarters looks as if it had been plucked straight from Silicon Valley: There are foosball tables, open workstations, and free food and beer on Friday afternoons.

On one of those afternoons last September, Chen was fine-tuning the algorithm that converts raw sensor data into meaningful information during ski jumps, such as height, speed, and body position. Not being a skilled skier himself, he tests his code tweaks by using a trampoline or hopping down the stairs. When he finishes a software upgrade, he hands it off to the "quality assurance team," a bunch of tech-savvy daredevil skiers and snowboarders.

The QA team normally does its testing on nearby Whistler Mountain or on Mount Hood, in Oregon, and sometimes Chen and the other engineers tag along. Sure, Chen says, it's awesome getting ski tips from the pros. But what he loves best about a long day on the slopes is his idea of an après-ski good time: retiring to the lodge to troubleshoot his code.
—ARIEL BLEICHER

PHOTOGRAPH BY David Ellingsen

[AUDIO]

ART OF NOISE: Bang & Olufsen's Geoff Martin shows off the company's speaker-measurement room, known as "The Cube," a 12- by 12- by 13-meter space where each speaker's output is precisely measured.

Der Tonmeister

GEOFF MARTIN BRINGS A MUSICIAN'S SENSIBILITIES AND AN ENGINEER'S PRECISION TO LOUDSPEAKER DESIGN

YOU LOVE MUSIC, yet you're also drawn to engineering, and you can't decide which to pursue. What to do? Why, become a *tonmeister*, of course.

That's what Geoff Martin did. No kidding: His official title is *tonmeister* of Bang & Olufsen, the Danish company that since 1925 has been showing the world that well-engineered audio and video equipment can also be beautiful.

The German word *tonmeister*, Martin explains, refers to someone who straddles music and engineering. "Once upon a time, if you wanted to do a recording, you needed to hire two people. One was a recording engineer, the geek who knew about acoustics, microphones, and electronics. The other was a producer who understands music and knew how to talk to the conductor and the musicians. A *tonmeister* is both of those people rolled into one."

At Bang & Olufsen, Martin works with engineers and designers to ensure that the components they produce sound really good. He's the ears of B&O, in other words. And given the understandably high expectations of the company's customers, who may be plunking down US $20 000 for a pair of loudspeakers, that's a pretty hefty responsibility.

PHOTOGRAPH BY Henrik Sørensen

Geoff Martin

IEEE Member **AGE** 43 **WHAT HE DOES** Works with acoustic engineers to design high-end audio systems; contemplates the future of sound. **FOR WHOM** Bang & Olufsen **WHERE HE DOES IT** Struer, Denmark **FUN FACTOR** Revels in discovering little-known surround-sound recordings, like Pink Floyd's "Dark Side of the Moon."

MARTIN SPENDS A LOT OF TIME in a soundproofed, windowless, vibration-isolated listening room equipped with various sets of B&O loudspeakers (commercial products as well as prototypes), a large but not gigantic flat-panel display, and some comfy chairs. When he closes the door, it seals with a satisfying *thunk*.

Martin's listening room is useful when he and his colleagues are conducting research for publication, but it's less helpful for designing actual products. "Most of our customers have living rooms that are much bigger than this–they have toilets that are bigger than this," he says.

Which gets to one of the great difficulties in engineering the perfect loudspeaker: You have no control over where customers will put it or what they'll play. "I have some of the strangest playlists in the world," Martin says. For example? "Metallica followed immediately by Gregorian chant going straight over to Stravinsky going to Lady Gaga."

Every B&O audio system has to play all that in all sorts of settings and always sound great. So during the design phase, each system is listened to and tweaked in a number of rooms, including Martin's kitchen at home. Problems that turn up–a resonance at 3 kilohertz, say–can be digitally corrected by adding a filter to the unit's digital signal processor.

IN A WAY, Martin has spent his whole life preparing for this job. He grew up in Newfoundland, where there's a strong folk-music tradition, and just about everyone he knew was musically inclined. "Back in those days if you couldn't play an instrument, it was a bit weird," he recalls.

As a boy, Martin took piano lessons and sang in church choirs. Then came a bachelor's degree in music from Memorial University of Newfoundland and graduate work, also in music, at McGill University, in Montreal. But his Ph.D. thesis, titled "A Hybrid Model for Simulating Diffuse First Reflections in Two-Dimensional Synthetic Acoustic Environments," was way more technical than most in his department. He earned money on the side as pipe organist, choir conductor, studio technician, and audio engineer.

In 2002, not long after Martin finished his doctorate, Søren Bech, an adjunct professor at McGill who worked for B&O, told him the company was looking for somebody with just his background. Martin applied, got an offer, and soon found himself relocating to the small town of Struer, in western Denmark, where the company is based.

Martin was hired to help design B&O's first automotive sound system. The team was starting from scratch. "We didn't even have a customer," he says. Given Bang & Olufsen's reputation in audio design, though, they knew it couldn't be your run-of-the-mill car stereo system.

After developing a 1000-watt, 14-speaker prototype, B&O scored its first car: the Audi A8, the luxury automaker's flagship. Then the real engineering started. "A car is a really bad place to put audio," Martin says. "It's noisy, none of the speakers are in the correct places, and none of the people are in the correct places."

On the other hand, he says, "I had almost surgical control over every [loudspeaker] driver, and I could put different filters, gains, and delays on each one." He eventually added 285 digital filters to compensate for the deficiencies in the listening environment.

Problems cropped up in unexpected places. "It turned out the seat belt mechanism in the middle backseat vibrated at 83 hertz, and it was quite close to the subwoofer," he says. "That caused me a lot of grief."

The car company expected maybe 5 percent of its model year 2005 A8 buyers to shell out the extra €6000 [about US $8000 in current dollars] for the Bang & Olufsen system. Four times as many did so. These days B&O's automotive systems can also be found in Mercedes-AMGs, Aston Martins, and BMWs.

Martin no longer works on cars, nor does he just work on upcoming products. "About half of what I do is to look at how we will be listening to music in 10 years–not what we are going to put into the next product, but what do we need to start thinking about for the product after that or the one after that?"

ONE MAJOR DRAW of the job is that it affords Martin and his family an enviable quality of life. When he joined the company, his fiancée was working in Ohio, and they debated over where to settle. What decided it? Denmark's government-supported child care, health care, and free public education through college were far more attractive than what they'd get in the United States or Canada.

Danish corporate culture is also far more accommodating. "We work 8 to 4, four days a week, and on Fridays we work until 3," he says. "Almost anything that doesn't get done by 4 can wait until the next morning. The expectation is that you go home, spend time with your family, and enjoy your life."

Which is not to suggest that Martin is a slacker. Indeed, he's an energetic perfectionist. "I'm never satisfied with the final product. There's never a point where I think, ah, that's great." There have been times, he says, when his colleagues thought a new model was ready to release, but his ears told him otherwise, and fixing the problem meant delaying the introduction. "I don't do it often, because there are commercial implications to pulling the emergency brake," he adds.

Clearly, Martin has found the perfect environment for his lifework–if you can really call it work. He doesn't. "Being a *tonmeister* is not so much a job–it's what you are." —JEAN KUMAGAI

[SOFTWARE]

Online Educator

MARCIA LEE SHAPES THE KHAN ACADEMY'S TOOLS FOR WEB-BASED INSTRUCTION

Marcia Lee

IEEE Member **AGE** 25 **WHAT SHE DOES** Builds tools for students for use on the Khan Academy website and for teachers who develop material for the site. **FOR WHOM** Khan Academy **WHERE SHE DOES IT** Mountain View, Calif. **FUN FACTOR** She gets to build tools that help people learn, without worrying about making money from it.

IN LATE AUGUST 2010, Marcia Lee, newly graduated from Stanford with a master's degree in computer science, packed her car and drove north from Silicon Valley for what she thought would be a fantastic job at Microsoft and an awesome apartment in Seattle. She turned out to be right about the digs but wrong about the work.

So after just five months, Lee quit Microsoft and headed back to Silicon Valley. The apartment she settled into there was nothing special, but the new job she found, at the Khan Academy, sang to her heart.

The Khan Academy educates millions of people online, and for free, thanks in no small measure to Lee's software. That code allows both students and teachers (or coaches, as the Khan Academy calls them) to navigate and interact with the site. Lee loves using her technical skills to help people. But she had to spend time at Microsoft before she grasped how much the human part meant to her.

BEFORE GOING TO MICROSOFT, Lee had spent a few months volunteering as a software engineer at Samasource, something she had also done briefly during school. The nonprofit organization provides people living in poverty in developing countries with work they can do over the Internet, using just basic English skills. She no longer had time for Samasource after she signed on with Microsoft as a program manager. But that was fine with her; she envisioned a long and busy career moving from one interesting assignment to another.

At Microsoft, she was placed on the team responsible for the company's Messenger server, the system behind Windows Live Messenger. Messenger server technology works in the background to make sure that all Microsoft's messenger apps play well together. Lee, whose master's specialization was in the field of human-computer interaction, found that the human element that mattered so much to her was missing. "I was just a little bit too far removed from the user-facing side of things," she says.

She also found the pace of software development at Microsoft frustratingly sluggish. A Silicon Valley native who had grown up on Internet time, Lee likes to see whatever she's working on mature quickly. But her project at Microsoft had timelines measured in years, not months.

Lee soon figured out that Microsoft was just not for her. She had a heart-to-heart talk with her manager in January 2011, and a couple of weeks later she walked out the door looking for greener pastures.

Her parents, both Chinese immigrants, weren't happy. They felt that a secure job at a big company was not something to be thrown away lightly. "In hindsight, I was a little bit bold," says the typically soft-spoken Lee. "I had no idea where I was going."

She settled temporarily into her parents' Silicon Valley house. And she started, once again, looking for a job.

This time, she had a good idea of what she wanted: to be part of a group that had a purpose beyond making money, perhaps something like Samasource, but with a mission she could more easily relate to. So she worked her Stanford network for leads, and eventually a friend of a friend forwarded her an e-mail

STYLIST: TIETJEN FISCHER

PHOTOGRAPH BY Gabriela Hasbun

message about a job opening at the Khan Academy.

Today, the Khan Academy is well known, at least in education circles. In early 2011, however, it was only four people working above a tea shop in downtown Mountain View, Calif. Its founder, Sal Khan, had yet to give the TED conference talk that brought him into the spotlight and prompted the TV news magazine "60 Minutes" to do the profile that brought his fledgling online academy to the attention of tens of millions of people.

Lee explored Khan's website before applying. The mission–"provide a free, world-class education to anyone, anywhere"–appealed to her. And the job posting described projects that would directly affect end users. She e-mailed her application, was interviewed via Skype, and met her coworkers for the first time on the day she started. She had wanted fast and nimble, and she had found it.

HER FIRST ASSIGNMENT was to develop math exercises. She worked with middle school teachers to formulate the kinds of challenges to present, then helped build software to generate new problems and offer hints on demand. Lee had to ensure that this software functioned well and made sense to the audience. "I don't have experience teaching sixth-grade math," she notes. But she did have youth: "Of anyone on the team, I was the closest to sixth grade."

Recently, she worked on the way users ask and answer questions on the site, developing a system to award badges to users whose answers others rate highly. These days, she's working on tools for the Khan Academy's faculty–the small group of people who create the videos–so they can more easily upload, edit, and categorize lessons and other material.

Lee professes not to envy one bit the lavish perks doled out at nearby Google and Facebook. Free gourmet meals and haircuts are nice, but not as satisfying to her as the knowledge that she's helping millions to lift themselves out of ignorance and, perhaps, poverty. "There are bigger problems in this world than not having a catered lunch," she says.
–TEKLA S. PERRY

[RENEWABLES]

Solar Sailor

CHRISTIAN OCHSENBEIN WAS THE ENGINEER ON BOARD THE ONLY SOLAR BOAT TO CIRCUMNAVIGATE THE GLOBE

INSIDE THE MAIN CABIN of MS *Tûranor PlanetSolar*, the first boat to travel around the world on sunlight alone, Christian Ochsenbein opens a trapdoor hidden beneath a seat cushion and crawls inside. He climbs down a dark tube and squats inside a long, narrow chamber–one of two pontoons keeping the catamaran afloat.

"We are now inside the 'engine' room," he jokes. This being a solar-powered boat, there is no real engine to see. He points out the propeller shaft, driven by AC motors, and at the opposite end, a vault that houses solar-charged batteries.

Ochsenbein is clearly impressed with the energy system, which had never been tested to such an extreme before the recent circumnavigation. As the vessel's onboard engineer, he got to know the system very well. It was his job to keep it from failing. Because if it had, he says, "it's game over."

Ochsenbein is a mountain boy at heart: He grew up in the Swiss city of Thun, surrounded by the whitewashed peaks of the Alps. But he was no stranger to the water. He swam competitively, eventually winning two bronze medals in the Swiss National Championships. His father, a chief technician at a shipyard on Lake Thun, introduced him as a youngster to the pleasures of yachting.

In secondary school, he took an apprenticeship with a small electronics company, where he made parts for trains, coffee machines, and electronic locks. There, he discovered an affinity for engineering–for the transformative process of creating a product out of little more than an idea and a soldering iron.

He went on to earn a bachelor's degree in electrical engineering and then got a job building industrial laser cutters for Bystronic Laser. But after two years at the company, uninspired by the monotony of rebuilding the same products a thousand times over, he left to find the next challenge.

It came, all right–and it was a doozy.

HE'D BEEN OUT OF WORK less than a month when he got a call from a fellow Swiss engineer named Raphaël Domjan, who was aiming to circle the globe with a solar-powered yacht. Two years under construction at a German shipyard, *PlanetSolar* was just weeks from completion, and Domjan was looking for an electrical engineer to oversee the ship's technical systems–its 38 000 photovoltaic cells, its 11 metric tons of lithium-ion batteries, its 120-kilowatt propulsion motors, and all its converters, connectors, and switches. Ochsenbein had the right skills, and Domjan liked his easy manner and team spirit. Would he join the expedition?

Ochsenbein wasn't sure how to respond. He'd never before spent time at sea and worried he'd get seasick. Most troubling, though, was the thought that he'd be responsible for handling any

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technical problems that cropped up on the journey. "When you're thousands of kilometers from the next island, you cannot just call an electrician to bring a tool or a spare part," he says.

In the end, he took the advice his grandfather had often given him on hiking trips into the mountains—that it's better to make yourself sick trying than to regret not having tried at all. Three weeks later, he traveled to the shipyard in Kiel, Germany, where *PlanetSolar* was built, and climbed aboard.

The 35-meter-long boat was unlike any he'd ever seen. Perched on a pair of enormous, talon-like pontoons, its massive central hull hovered above the waves. Jet-black solar panels tiled its deck and extended out over its sides, like the wings of a giant bird of prey.

"People always say that it looks like a spaceship," Ochsenbein says. Months later, he recalls, when *PlanetSolar* had anchored in the Marquesas Islands, smack-dab in the middle of the Pacific Ocean, a local woman told him that when she saw the ship gliding into the bay, she screamed because she thought it had come from Mars.

From Kiel, Domjan and his crew navigated *PlanetSolar* to Monaco, where their world tour would officially start. The shakedown voyage provided Ochsenbein with a crash course on the boat's electrical and power-control systems. Engineers from Drivetek, the Swiss company that had built the systems, were on board to show him the ropes. He paid close attention, knowing that when the real journey began, he would basically be on his own.

On 27 September 2010, the crew departed Monaco with much fanfare. They began the 19-month world tour by heading west across the Atlantic to Miami, then proceeded on to Cancún, Mexico, and Cartagena, Colombia, before passing through the Panama Canal toward the Galapágos Islands. From there, they hopped various far-flung Pacific islands to Brisbane, Australia, then zigzagged northwestward, skirting the coasts of Southeast Asia, India, and the Arabian peninsula before squeezing through the Suez Canal into the mild Mediterranean Sea. From over the horizon, sunny Monaco lured them like a homing beacon.

IT TOOK OCHSENBEIN some time to adapt to life at sea. He woke each morning before 2 and navigated the ship for 3 hours until 5 a.m. During the day, he cooked and cleaned. He checked the motors, pumps, and other electrical systems and performed any needed maintenance. Then at 2 in the afternoon, he climbed the narrow staircase onto the bridge and took the helm again until 5 p.m.

Although he soaked in much natural beauty during the voyage, there were some discomforts. The ship had no cooling system, and the heat absorbed by the solar panels often raised the temperature inside to as high as 46 °C (115 °F). "You're sitting in a chair wearing a T-shirt and shorts and doing nothing, and you're sweating like you were running like hell," Ochsenbein remembers. The panels themselves would heat up to 85 °C, hot enough to begin melting the rubber soles of the sailors' shoes. Sometimes, during peak heat, "we put down a frying pan and made some eggs."

Yet despite the hardships, Ochsenbein embraced solar travel. "It's a way of [living in] freedom," he says. Without diesel engines or sails, *PlanetSolar* was so quiet he once heard a whale breathing. Sometimes on warm evenings, he would sit on one of the ship's supporting pontoons, dangling his feet in the teal water while trailing a line.

Christian Ochsenbein

IEEE Member **AGE** 28 **WHAT HE DID** Minded the electronics on a solar-powered yacht. **FOR WHOM** *PlanetSolar* **WHERE HE DID IT** The oceans of the world **FUN FACTOR** Visited far-flung, exotic islands that are off-limits to diesel-powered boats.

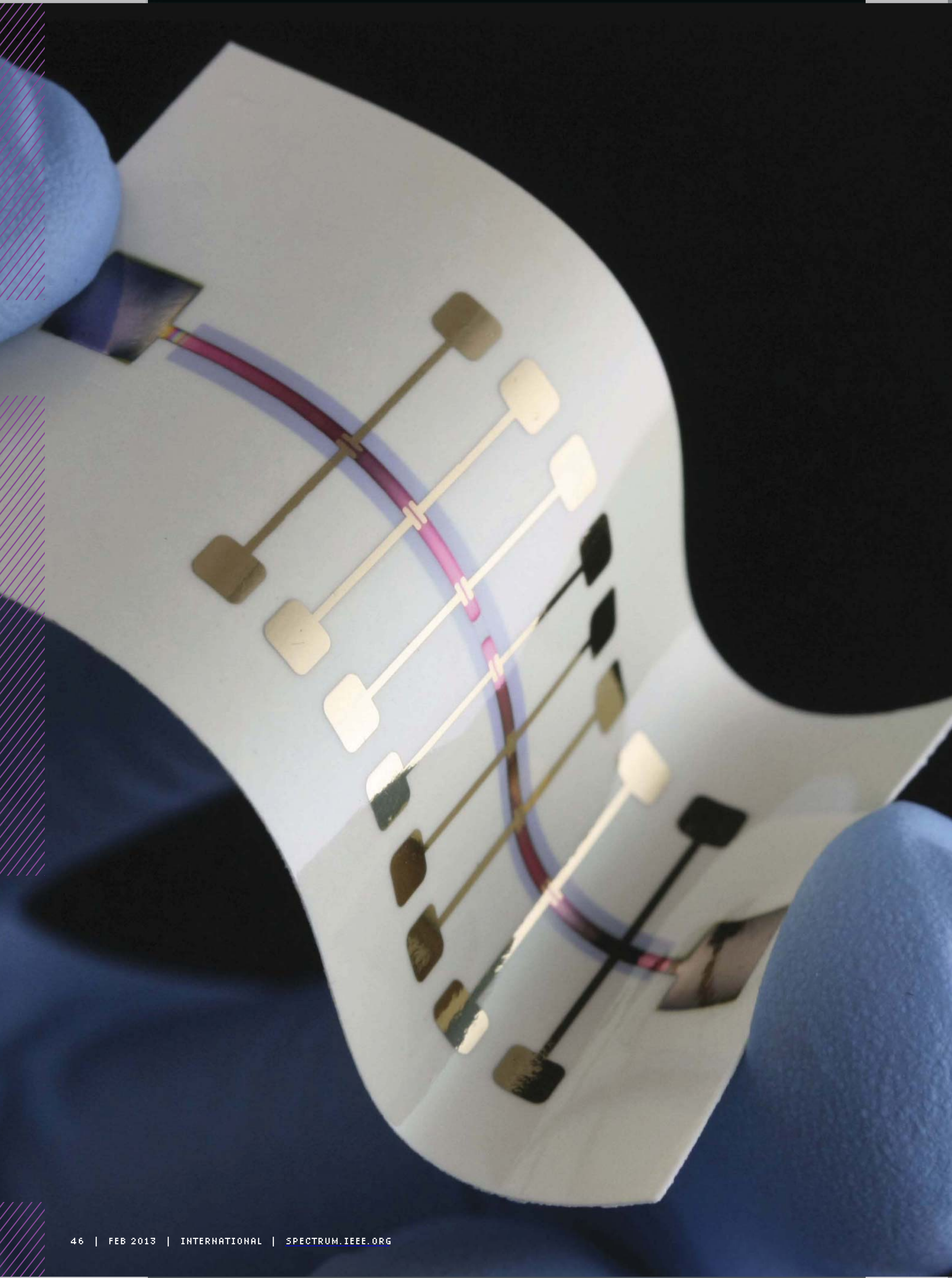
It wasn't always smooth sailing, though. While crossing the Gulf of Aden, off the Horn of Africa, the crew and six former French soldiers escorting them were on edge for four weeks, knowing that Somali pirates might try to hijack their exotic €12.5 million vessel. Three times over the course of the trip, a solar cell shattered because someone fell on it. Twice a propeller broke.

But such problems were rare and always low-tech. To Ochsenbein's relief, the power systems functioned flawlessly. "We crossed the largest, wildest oceans in the world with 100 percent solar power," he boasts.

A fleet of press boats and cheering crowds greeted *PlanetSolar* as it glided into Monaco harbor on 4 May 2012. Even the diesel-guzzling megayachts blew their foghorns in celebration.

Disembarking, Ochsenbein looks exhausted, but he's beaming. "We went to terra incognita with solar technology," he says, "and we came back." —ARIEL BLEICHER

PHOTOGRAPH BY Antoine Doyen



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CIRCUITS ON CELLULOSE

PAPER ELECTRONICS COULD PAVE THE WAY TO A NEW GENERATION OF CHEAP, FLEXIBLE GADGETS

BY ANDREW J. STECKL

YOU WAKE UP with a heavy head. Was it the half dozen glasses of champagne last night or are you getting sick? In your bathroom is a little strip of paper that can tell you for sure. You place it on your tongue and after a few seconds, you pull it back to see the bad news: There's a small green dot next to the word "flu." When you fish your doctor's business card out of your wallet, you notice it looks different from the last time you looked at it. The phone number for his office was originally black. Now it's displayed in blinking red letters, a sign that the number was changed recently.

The electronics in this scenario are not far off; in fact the basic technological breakthroughs needed to make them work have all been achieved in the past few years. At the moment the costs are still too high for them to be used in things like business cards or package labels, but remarkable advances in materials science and simpler fabrication methods are setting the stage for a whole new breed of cheap, bendable, disposable, and perhaps even recyclable electronics. And some of the most exciting work in this field is happening with paper.

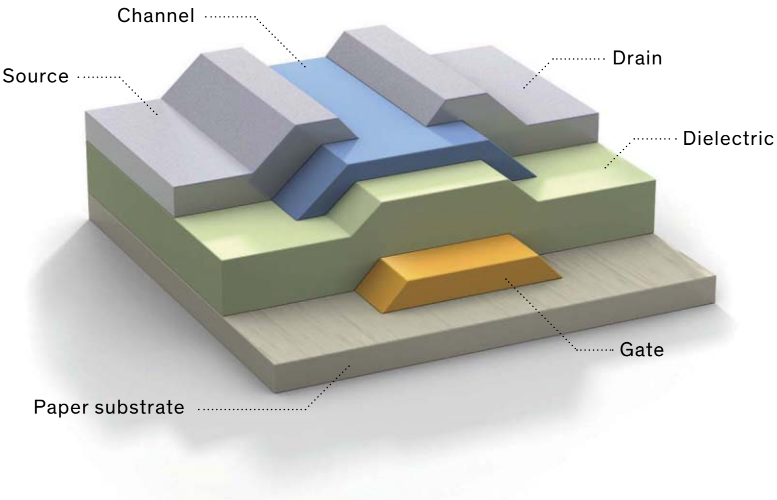
At first glance, paper might seem like an unlikely front-runner in the flexible electronics race. Straight off the shelf, the material isn't nearly as rugged as plastic or as smooth as new, bendable forms of glass. And at a microscopic level it's just a tangle of cellulose fibers, hardly the sort of structure that's ideal for making a bunch of finely featured, identical circuit components.

But paper actually has a lot going for it. It's lightweight, flexible, biodegradable, and it comes from a renewable resource. It's also extraordinarily adaptable: With the right set of additives and manufacturing processes, paper can take on a seemingly endless range of properties. It can be made hydrophilic or hydrophobic, porous or watertight, opaque or nearly transparent, delicate or strong, coarse or about as smooth as glass.

Paper electronics also have the potential to be extraordinarily cheap. The material itself is intrinsically inexpensive; conventional varieties cost about a tenth as much as plastic film. Even the special paper that's tailor-made for electronics costs, area for area, about 1 percent as much as silicon. Roll-to-roll presses can print microscopic features on wide reams at speeds of up to 30 meters per second–about three times as fast as the Olympian Usain Bolt can run.

When my research group at the University of Cincinnati first started working with paper in 2008, we weren't thinking too broadly about the material's potential as the base layer, or substrate, for electronics. We were originally interested in a relatively narrow application, what might be called "e-paper on paper," essentially electronic displays built directly on paper. The initial proof-of-principle experiment worked far better than we expected, and in the years since, I've become convinced that paper's potential could be just as broad (if not as deep) as silicon's has turned out to be. Paper has already shown promise as a substrate for sensors, biological assays, RF antennas, batteries, circuit boards, and smart packaging labels. In the next few years, we'll start to see the first gadgets based on this technology make their way out of the laboratory and into the hands of consumers and business users.

Transistors



FLEXIBLE STACK: Transistors on flexible substrates can be built using organic or inorganic semiconducting channels. This schematic illustrates a way of making an organic switch.

IN A TECH WORLD dominated by plastic, glass, and silicon, it may come as a surprise to learn that research into paper electronics actually dates back nearly 50 years. In the late 1960s, Peter Brody's group at Westinghouse Electric Corp. experimented with paper, among other materials, as a substrate for thin-film transistors, the sort that could be built into switching arrays to control individual pixels in a liquid-crystal display.

Even then, before a wealth of coating and processing innovations came on the scene, paper had a number of attractive attributes. Chief among those was its quality as an electrical insulator. Paper generally boasts a resistivity of some 10 billion ohm-centimeters, about 100 000 times the intrinsic resistivity of silicon. That means the material should, in theory, work quite well as a substrate for electronic devices. It resists the flow of current so well that it effectively eliminates one of the most common pathways electrons use to sneak across a transistor when it's supposed to be off.

That isn't to say paper is the ideal material on which to build transistors. Materials like glass and traditional semiconductors are easy to manufacture with variations in surface height of a few nanometers or less. But height variations in paper range from at best a fraction of a micrometer up to several micrometers, depending on the fiber size and how well those fibers commingle to form a flat mat. Electronic devices built on such an irregular surface are likely to vary greatly in performance, and a sizable proportion will not work at all.

Despite that, about five years ago, as interest in electronic readers and flexible reflective displays took off, researchers began to explore paper as an electronics substrate. The potential payoff was big: If they could build the back-end circuitry needed to control pixels, they'd be halfway to creating a changeable reflective display that naturally has the look and feel of paper (and is just as thin, lightweight, and flexible).

Since then, about a half-dozen research groups have made considerable headway in constructing paper-based transistors. They've used either inorganic semiconductors like silicon or indium gallium zinc oxide for the current-carrying channels or organic materials like pentacene or P3HT. A good part of this progress has followed from finding

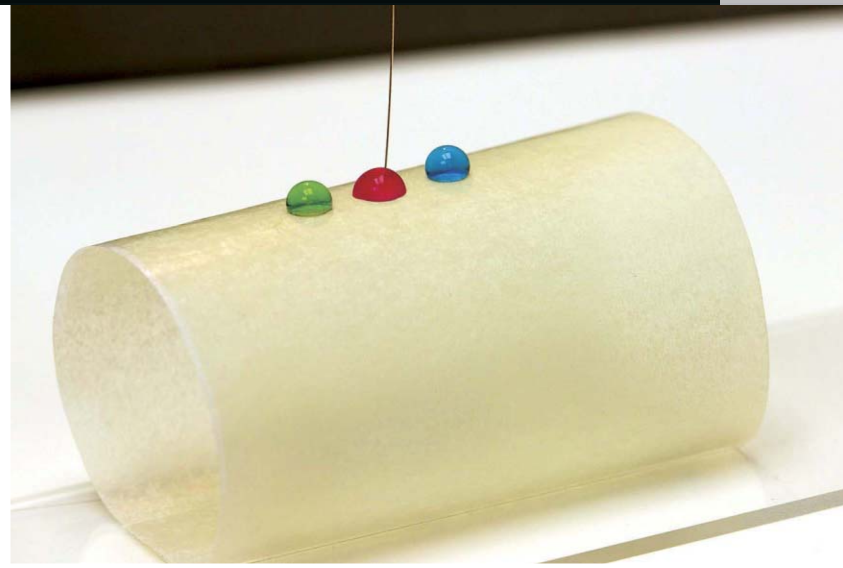
PREVIOUS PAGES: ADAM ZOCCO/ANDREW J. STECKL/UNIVERSITY OF CINCINNATI

ILLUSTRATION BY Emily Cooper

or developing the right kinds of paper. The best are those that have special polymer coatings that help fill in troughs in the surface and seal the paper to prevent chemical degradation during the fabrication process.

Paper would simply combust at the temperatures used to grow and treat the crystalline films used in traditional semiconductors, so inorganic paper-based transistors are typically made from amorphous, noncrystalline films. These can be formed at a lower temperature using the standard techniques of depositing a material in a vacuum, such as evaporation or sputtering. This fabrication strategy is straightforward, but the resulting transistors tend to embrace paper's inherent textural variation, the result being that the voltage needed to get current to flow in them can be a dozen times as much as what's needed to move electrons through transistors built on glass or silicon. John Rogers's group at the University of Illinois at Urbana-Champaign, for example, has been perfecting an alternative approach in which circuits are built on silicon and then transferred to paper (or other substrates) once they're finished. This method tends to create better-performing circuits, although the fabrication process is considerably more involved, and it's also more costly, because it would start with a silicon wafer.

When it comes to mass production, however, the organic semiconductors may be the way to go. Unlike inorganic materials, organic compounds can be dissolved in fluid and deposited on paper using roll-to-roll printers, just as with ordinary ink. But this approach still faces some obstacles. For one, the transistors tend to be slower, due to the intrinsic properties of organic semiconductors. And organic switches are naturally more sensitive to environmental conditions. Oxygen and water vapor, for example, can degrade or even open up a gap between an organic material and a metal electrode through chemical degradation by oxidation or by partially dissolving the structure. Surface treatments can help make paper—which naturally sops up moisture from the air that could affect the device built on top—relatively impermeable. But a fix is still needed to ensure that organic circuits perform well over long periods in relatively humid environments.

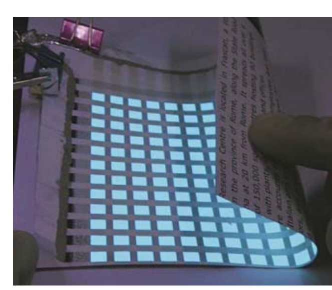


Pixels

THIN-FILM CIRCUITS BUILT on paper are too slow to be considered for general purpose computing, but they are an attractive means for controlling and interacting with "outward-facing" devices such as sensors, displays, and energy-harvesting gear.

Building such devices on paper can be just as challenging as building back-end electronics. But there has been a lot of progress, particularly in the relatively inexpensive and low-power realm of reflective displays. One promising approach is the electrochromic display, which uses pixels made of a conducting polymer. If a sufficient voltage is applied to such a pixel, electrons will be knocked off and the optical properties of the polymer will change, turning it from, say, dark blue to transparent. This approach, which was pioneered by Magnus Berggren's group at Linköping University, in Sweden, has many advantages. For one, it requires just a few volts to operate, and it's structurally fairly simple. But there are a few drawbacks. The color palette is limited, and the switching speed is quite slow. It can take anywhere from a fraction of a second to several seconds to complete pixel transformation, which makes the display unsuitable for full-motion video.

At the University of Cincinnati, my group has been working on adapting an alternative display approach called electrowetting, which is traditionally used with glass. Electrowetting works by confining liquids between two surfaces and then altering their surface tension, using an applied voltage. Altering the surface tension causes the colored liquid to either spread out and reflect light or ball up and allow the light through. Paper hardly seems a natural fit for this technique. Electrowetting displays typically use liquids like water and oil that are readily absorbed by paper. Pixels also need to be built on a very smooth, glass-like surface to ensure reliability and fast response. With a rough surface, it's very hard to guarantee that liquids will move where they're supposed to every time.



ON DISPLAY: Paper can be used to make displays that either reflect incoming light or emit their own. One way to make a reflective display is to alter the surface tension of liquid pixels [top]. Organic light-emitting diodes can also be built on paper to make displays that glow [bottom].

We first tried the same sort of wax-coated papers that you might find in your kitchen cupboard, standard "smooth-finish" commercial papers, and also a translucent paper called glassine. Although the surfaces of all these paper

TOP: DUK-YOUNG KIM/ANDREW J. STECKL/UNIVERSITY OF CINCINNATI; BOTTOM: JIN-YOUNG KIM/SUNGKYUNGKWAN UNIVERSITY

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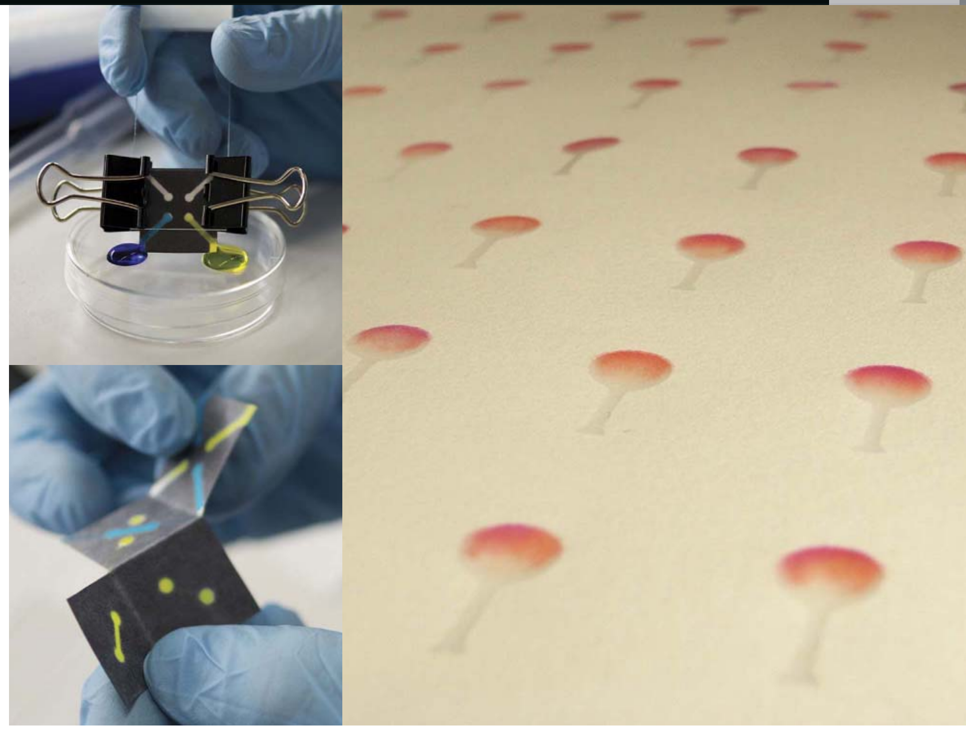
types resist water, they eventually did absorb the liquid. Then we were contacted by the Boston-based Sappi Fine Paper North America, which had created a polymer-coated paper with an average surface roughness of a couple of nanometers, just a little higher than that of glass. That seemed to be just the thing. With that material, we were able to make reliable pixels with switching times as short as 10 milliseconds—nearly suitable for video. We are now working to develop paper-based displays using electrowetting. We think this approach might be ideal for smart labels on packages that could, for example, show videos about how the product is to be used, or for displays—containing vital information for soldiers in the field—that can be rapidly destroyed if necessary.

For both displays and back-end electronics, fabrication still remains a problem. The fastest, cheapest way to build paper electronics is to use a roll-to-roll printer. But the state-of-the-art resolution of these machines is currently about 10 micrometers. So flexible electronics fabricated with these machines would have feature sizes about the same as those of silicon-based chips in 1971, when microprocessors had about 2000 transistors. Improving this resolution without sacrificing printing speed will take years and significant investment.

That being said, size isn't everything. Displays—particularly if they can be constructed economically—can still be quite readable and attractive even if they're constructed from components that are much larger than those needed for advanced integrated circuits. (After all, today's state-of-the-art tablets and e-readers boast pixel sizes of about 100 μm, which is about 10 000 times as large as the minimum feature sizes needed to build state-of-the-art memory chips.) Some circuit components need larger features to function well. Radio-frequency ID tags, for example, need relatively large antennas to be able to pick up and transmit electromagnetic waves with radio wavelengths. Even the smallest RFID chips reported to date are about 50 μm on a side. And high-voltage power electronics tend to perform better when they're made bigger, because spreading a load over a large area reduces the chance of electrical breakdown. This is a realm where paper has already been used for many years, as an insulator in transformers.



CLOCKWISE FROM RIGHT: XU LI/WEI SHEN/MONASH UNIVERSITY; ALEX WANG/UNIVERSITY OF TEXAS AT AUSTIN (2)

Microfluidics

THOSE OF US building paper-based electronic devices and displays are, to a certain extent, working against paper's intrinsic properties. But there is one potential application area where paper is clearly a natural fit: microfluidics.

Microfluidic devices work by transporting liquids from one spot to another. In the realm of biomedical technology, they're particularly useful because they allow you to perform tests like DNA analysis or toxin detection on small liquid volumes, which cuts down on costly chemicals and reagents and greatly reduces the amount of bodily fluids that must be extracted from patients. To date, most microfluidic units have been high-precision affairs that rely on plastic feed tubes and externally powered pumps, which can take up a fair amount of counter space. If patterned correctly, paper could be used to perform similar tests without these external accessories. The narrow channels between fibers in paper excel at drawing in water and other fluids automatically by capillary action.

Some companies have already taken advantage of this liquid-wicking capability to create disposable pregnancy and blood-sugar tests. But recently the emphasis has shifted to a "bottom up" approach. Instead of making inexpensive versions of specific tests, researchers are now trying to develop a general class of paper-based microfluidic systems that can then be adapted to make a variety of different tests, for such tasks as monitoring liver function or diagnosing tuberculosis. If done right, these tests could be compact, self-contained—and cheap. They could also be used without a great deal of training, at home or out in the field, and easily disposed of by incineration after one use.

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Two of the pioneers in this field are George Whitesides at Harvard University and Paul Yager at the University of Washington. Both have benefitted from early and sustained support by the Bill & Melinda Gates Foundation for developing simple and very-low-cost diagnostic devices that do not require special skills or facilities. Their groups have advanced several simple and elegant approaches to forming paper microfluidic devices. One approach relies on a wax-based patterning process, which uses an inkjet printer to place features on paper with a wax-based "ink." After printing, the paper is heated to drive the wax though the entire thickness of the material. Because the wax-impregnated re-

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CHANNELING LIQUIDS: These basic microfluidic sensors [opposite, right] are built on filter paper. Straight channels lead to circular sensor regions that turn red in the presence of nitrogen dioxide. A single sample can be tested in multiple ways as it moves through a 3-D microfluidic device, like this one [opposite, left], which was built through folding.

gions are hydrophobic, fluid flow is restricted to wax-free regions. Wicking eventually guides the liquid to be tested into dry "compartments" containing chemical reagents or biomarkers. If the right combination of compounds is present, a chemical reaction takes place, producing a color change that the user can then read. Three-dimensional versions of these units have been developed in order to create compact packages that can perform multiple tests, in different layers, on the same sample or else redundant tests to reduce the chance of a false result. One recent innovation comes from Richard Crooks's group at the University of Texas at Austin, which found a way to construct many-layered paper fluidic devices out of a single sheet of paper. The team's origami-like approach starts with a two-dimensional hydrophobic pattern that is formed using photoresist. After a few selective snips with scissors and some folding (think paper doll construction), a multilayered square can be assembled without tools. In the resulting assembly, overlaid openings allow fluid to flow up through as many as nine layers.

These paper-based tests have already spawned spin-off companies and nonprofits and will probably be the first paper-based technology to be commercialized. I expect they could eventually be augmented with communications circuitry and some logic to make remote sensors. But there is still much to learn about the actual fabrication costs of these assays, as well as practical properties like shelf life, sensitivity, and the reproducibility of their results.

Integration

THE DISPLAYS AND microfluidic systems I've described are far from the only applications being explored. My group and others, for example, are actively building light-emitting devices on paper to make luminous displays [see images, "On Display"]. Others are investigating novel ways to construct flexible RF antennas attached to curvilinear surfaces that boost their performance. Of course, regardless of what we choose to build, paper electronics will always be limited unless we can find a way to deliver power to the devices in a way that's just as mobile, thin, lightweight, and flexible as paper itself. What we'd really like to do is build batteries, capacitors, or photovoltaic cells directly onto the same paper that bears the devices.

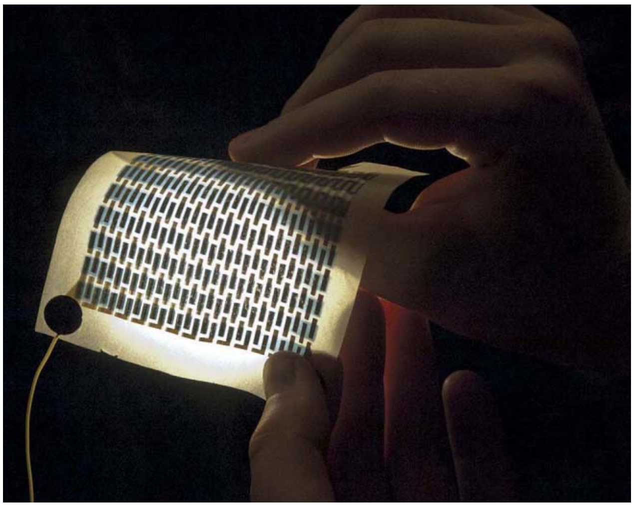
One potential way to store energy on paper is to take advantage of its long, thin cellulose fibers, which offer a lot of surface area that could potentially be used to store charge. Paper can be soaked with electrolytes to make a variation on the traditional battery. Alternatively, it can be coated with inorganic metal or carbon to store charge. The work is far enough along that it is being pursued commercially by firms such as the Paper Battery Co., in Troy, N.Y., Power Paper, in Israel, and Enfucell, in Finland. The storage specifications already seem promising: a 1-millimeter thick, 10- by 10-centimeter square patch can store a few hundred milliampere hours at 1.5 volts, about 10 to 20 percent the capacity of a typical AA battery.

Once all these components—power, back-end electronics, and front-end devices—are in place, I believe it will be possible to develop fully integrated, complete systems on paper that can power themselves and communicate with the outside world.

But finding ways to perform this integration will be a significant challenge. The ideal paper substrate for back-end circuitry might be very different from what's required to build, say, a front-end display or marry a microfluidic device with logic and communications circuits. Certain features, in particular the wires used to connect components, are especially fragile and will have to be carefully constructed, probably using materials and geometry different from those in conventional rigid integrated circuits.

But think of the possibilities if we succeed. We could fill an important economic gap in the technological spectrum of electrical devices, between the low-tech realm of incandescent lightbulbs and electric motors and the high-tech world of computer chips and flat panel displays. Although the cost of making an individual transistor has been declining for decades, the overall fixed costs of materials, fabs, and equipment are substantial and growing. We need a fundamentally new approach if we want to shake up the industry.

Paper is likely to emerge slowly in electronics: You'll see it first in markets where low cost—not high performance or small area—is the main consideration. Along the way, paper will face competition: Plastic is more rugged and electronics-friendly, and glass can now be made so thin and bendable that it's not impossible to imagine it could one day be fed into roll-to-roll machines. Despite this, paper has the potential to extend the reach of electronics into areas we might never have considered before, offering consumers a much wider range of choices when it comes to performance, reliability, and price. On paper (if you'll pardon the pun), there's little reason to think that this technology will stay in the lab for long. ■



PATRICK GILLOOLY/MIT

PAPER POWER: Flexible, foldable arrays of solar cells can be built on a paper substrate using vapor deposition. The solar array pictured here incorporates five layers and uses organic photovoltaic materials to convert light into electricity with roughly 1 percent efficiency.

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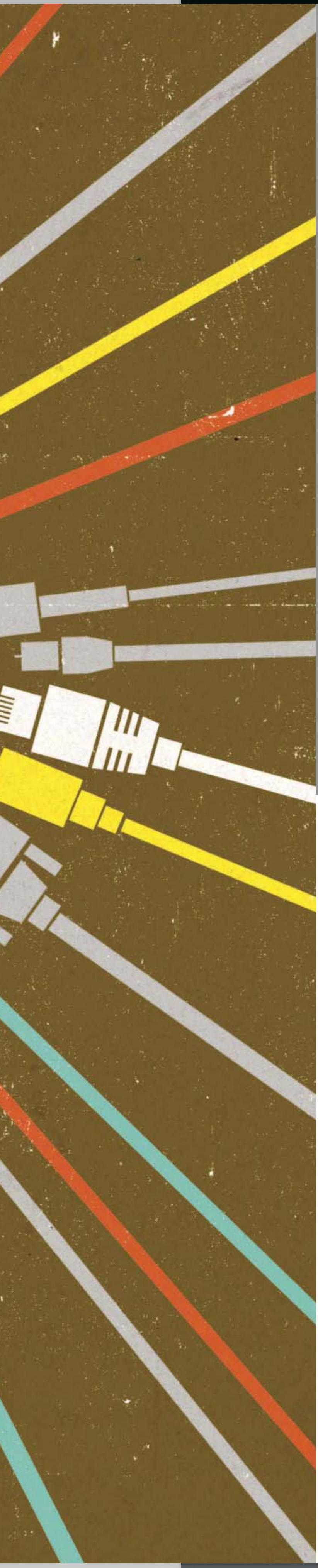
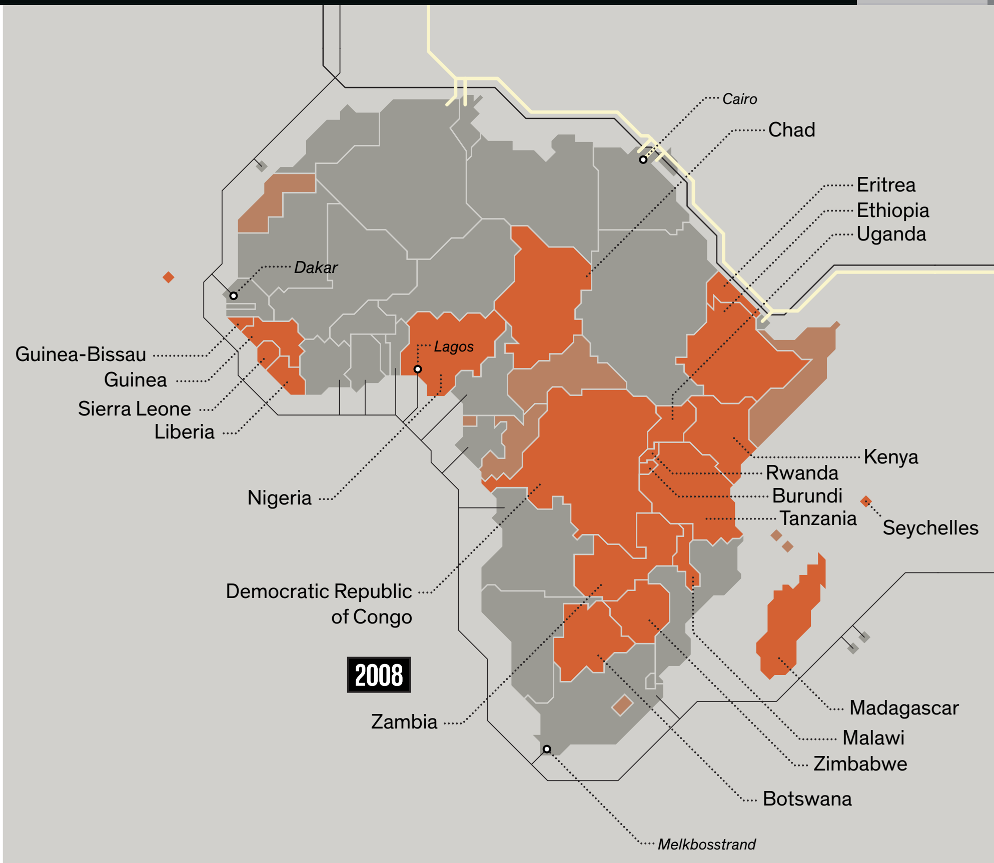


PINGING AFRICA

A decadelong quest aims to pinpoint the Internet bottlenecks holding Africa back

By R. Les Cottrell

THE UNIVERSITY OF KINSHASA, the largest university in the Democratic Republic of Congo, has nearly 30 000 students, faculty, and research staff—but only 800 computers. And although its internal data network is fast enough to support on-campus e-mail, virtual library access, and online coursework, its link to the outside world is no better than that of a typical household in the United States or Europe. • When I visited the university about a year ago, the restricted capacity meant that only 200 senior staff had Internet privileges—for whatever those were worth. I was able to go online for a short time, but the connection was barely usable. Web pages timed out or loaded so slowly that after about 10 minutes, I simply gave up. • Regrettably, the situation in Kinshasa is familiar to millions more schools, organizations, and communities in emerging parts of the globe. And the technical gap between developed and developing regions only widens the economic one. Without these connections, many developing countries miss out on innovations that offer higher standards of living, such as telemedicine, remote learning, and online commerce.



Football and Broadband

The telecommunications needs of the 2010 FIFA World Cup in South Africa helped bring a plethora of new international subsea cables to sub-Saharan Africa. As data from the PingER project show, the additional capacity has allowed many countries to upgrade from satellite to terrestrial links.

Nowhere is this disparity felt greater than in Africa. Less than 16 percent of Africans have access to the Internet, according to the latest market research. Compare that with 63 percent of Europeans and 79 percent of North Americans. Even in Asia, where Internet usage ranks second to last among the seven major world regions, the penetration rate is almost twice the rate in Africa.

Part of the problem is poor network performance. The total bandwidth available to shuttle data between African countries and the rest of the world in 2011 was less than 1 terabit per second. That's about one-seventieth of Europe's international bandwidth capacity. Making matters worse, the price for bandwidth in Africa is cripplingly high. While a university in Germany might pay about US $4000 per month for 1 gigabit per second of bandwidth, a school in Kenya can expect to pay $200 000 for the same service.

Yet while Africans continue to face huge technological disadvantages, conditions have nonetheless improved dramatically over the past few years. Since 2009, Africa has seen unprecedented upgrades to its broadband infrastructure. Remarkably, one of the biggest drivers was a single popular event: the 2010 FIFA World Cup. The celebrated tournament attracted more than 3 million football fans to Johannesburg that year. It also brought television crews and newscasters, whose telecommunications needs greatly exceeded what South Africa could have provided just two years before.

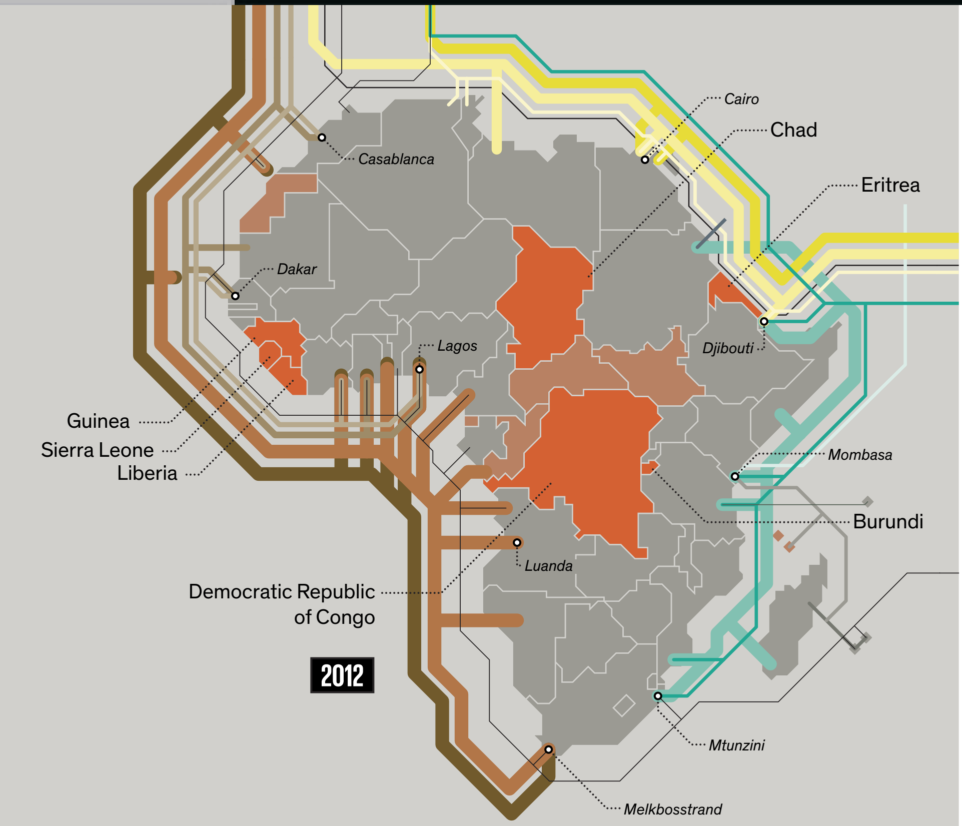
In 2008, Africa had only three fiber-optic links to the global Internet: two in the north and one in the west. But by the first match of the World Cup in June 2011, two additional international subsea cables had made landings up and down Africa's eastern and western shorelines, and three more would be completed before the end of the year. Since then, telecoms, governments, and aid organizations have invested billions in additional submarine cables and terrestrial networks across the continent.

So has Internet availability improved in landlocked as well as coastal countries? Or is it merely falling behind at a slower rate than before? Where besides the University of Kinshasa are there still significant bandwidth bottlenecks? To answer these questions, we need a cheap, reliable way to measure Internet performance at various places throughout Africa. And we need to compare the results with data from other regions and track changes over time.

That's exactly what the Ping End-to-end Reporting, or PingER, project does. I lead the project at the SLAC National Accelerator Laboratory, in California, with help from a handful of students and colleagues at the National University of Sciences and Technology (NUST) in Pakistan and at the International Centre for Theoretical Physics (ICTP) in Italy. But PingER's reach is truly global.

Using the simple and common "ping" test, we regularly measure how well data is flowing, if at all, between pairs of hosts–typically Web servers at distant universities. Since PingER's start nearly two decades ago, we

OPENING ILLUSTRATION BY **Dan Page**



Major Subsea Cables

West Coast	Date Active	Capacity
SAT 3/SAFE	2001	340 gigabits
MaiN OnE	2010	1920 gigabits
GLO-1	2010	2500 gigabits
WACS	2011	5120 gigabits
ACE	2012	5120 gigabits
East Coast		
Seacom	2009	1280 gigabits
EASSy	2010	4720 gigabits
Mediterranean		
SEA-ME-WE 4	2005	1280 gigabits
EIG	2011	3840 gigabits

Minimum Round-Trip Time

For a data packet to travel from the United States and back.

- < 400 milliseconds (indicates terrestrial Internet)
- No data
- > 400 milliseconds (indicates satellite Internet)

PING'S UBIQUITY AND EASE OF use make it especially well suited to widespread Internet monitoring, particularly in underdeveloped regions such as Africa where more advanced applications may be impractical.

The inventor of the tool, the late American computer scientist Mike Muuss, remembered writing the original code as "a little thousand-line hack" during a single evening in 1983 to troubleshoot "odd behavior" on the computer network at the U.S. Army's Ballistic Research Laboratory, in Maryland. His program sent a small data packet known as an echo request to an Internet Protocol address, typically a remote server or network node. If the target address was reachable, it sent back the same data, and the program recorded the time it took for the round-trip journey. The echoing action of the data probe reminded Muuss of the percussive sound pulse that sonar systems use to detect objects underwater, and so he named the program after that sound–ping.

The ping program can tell us a lot about the health of an Internet connection. By sending several echo requests in short succession, we can determine each packet's round-trip time (latency), the variability of these times (jitter), and the percentage of packets that never return (loss). High jitter or high loss typically indicates that a network path is heavily congested or there isn't enough bandwidth to handle the traffic.

When I first started PingER in 1995, I had no intention of using ping to address network deficiencies in Africa. As the head of networking at SLAC, I set up the system simply to test connections between the laboratory and several dozen research institutions worldwide that were collaborating on BaBar, a physics experiment whose aim was to study properties of subatomic particles. To analyze results, the BaBar collaborators had to share enormous data sets, which they had to be able to transfer quickly and reliably. PingER let me keep tabs on how parts of the network were performing and root out any problems.

Over the next half decade, as word of PingER's value spread, I extended monitoring to hundreds more physics laboratories and science centers across the globe. But the project didn't take a humanitarian turn until 2001.

That year, while visiting the ICTP in Italy, I met two staff physicists–Hilda Cerdeira, who grew up in Argentina, and Enrique Canessa, who hails

have set up close to 100 monitoring hosts around the globe, most of which now collectively observe about 900 target hosts in 164 countries. The data are delivered daily to three archive sites, in the United States and Pakistan, and made available online.

These measurements paint a fascinating history of the Internet's growth as seen from many different vantage points. They also reveal the impact on Internet performance of major world events, such as the 2011 uprisings in Egypt and Libya, and of major infrastructure upgrades, such as when many sub-Saharan countries switched from satellite to terrestrial links in 2009 and 2010.

Ultimately, by quantifying the digital divide between world regions and across time, we can better understand where and how to bridge it.

MAP BY L-Dopa

from Chile. Bolstered by the ICTP's mission to bring first-class science and technology to developing countries, they were helping many communities, mostly in Africa, to build computer labs and wireless networks. They told me they wanted to know how well the networks were working, and they thought PingER was the perfect tool for the job. They offered to help expand the project to those parts of the world that needed it most. Within the next year, we began establishing monitoring and target hosts in countries as diverse as Bhutan, Ecuador, Jordan, and Rwanda.

I soon got my first real glimpse of just how much of a difference PingER could make. In 2004, I started working with engineering students at Pakistan's NUST to help them set up a PingER monitoring site to assess performance on the then year-old Pakistan Educational Research Network (PERN). The network's providers and backers touted its bandwidth of 155 megabits per second–impressive at the time. But PingER revealed that the "last mile" links to universities were dreadful. These bottleneck connections funneled data at no more than 1 Mb/s, causing long delays and high packet loss.

During one of my many visits to the university, I presented our findings to the chairman of Pakistan's higher education commission, Atta-ur-Rahman, who was preparing to fund the next major upgrade to PERN. He clearly took PingER's lessons to heart. When construction of PERN2 began in 2009, its plans included extending high-speed, 1-Gb/s data links all the way to university data centers.

LOOKING AT PINGER DATA FROM AFRICA, it's clear that although Internet performance is improving, it still lags the rest of the world. Packet loss, for example, remains higher than in any other region except Central Asia–which includes Kazakhstan, Tajikistan, and three other republics of the former Soviet Union. What's encouraging, however, is that loss rates in Africa have begun to drop below 1 percent in the past couple of years. The threshold is important because it means that many connections can or may soon support real-time communication services, such as video streaming and Voice over Internet Protocol (VoIP) calls.

Round-trip latency has similarly improved in recent years, most dramatically in African countries that have switched from satellite to terrestrial links. Many of the upgrades followed the landing of new submarine cables prior to the World Cup in 2010. Not only did the cables vastly expand international data capacity on the continent, they also introduced competition, which drove down the price of data transmission. Through PingER, we can see that since 2008, more than a dozen sub-Saharan countries have mostly abandoned satellite Internet, after which the latency of their connections suddenly dropped by roughly half [see map, "Football and Broadband"]. These upgrades have helped establish several high-speed national and regional research and education networks in Africa, similar to Internet2 in the United States or the GÉANT network in Europe.

PingER data can also be used to assess the quality of a voice connection, which telephone companies originally determined by placing callers in a quiet room and having them rate audio quality from 1 (worst) to 5 (best). For a VoIP network, the International Telecommunication Union has established a standard for calculating this mean opinion score, or MOS, based on latency, loss, and jitter. A network with an MOS greater than 3.5 can generally support VoIP services such as Skype.

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By tracking MOS results over time, we can identify the approximate date when Internet-based calling emerged between one region and another. For example, it appears that VoIP calls between North America (at SLAC) and Latin America were possible beginning in 2003. Similarly, VoIP calls to the Middle East were first possible in 2004, and calls to South Asia started in 2009. Not coincidentally, 2009 was also the first year that I and my student collaborators in Pakistan began using Skype for conference calls. I remember the event fondly because it meant I could stop paying $1 per minute for a regular long-distance connection.

Africa's Internet still has a way to go before most communities there can take advantage of these savings. In fact, Africa remains the only region whose average MOS score hasn't yet surpassed 3.5. I suspect, however, that considering recent progress in other measures, this will begin to change in the next few years.

Another useful performance metric is throughput, a function of loss and round-trip latency that approximates the rate at which data is delivered between pairs of hosts. Given Africa's recent improvements in both loss and latency, it's no surprise that its throughput is increasing. But until recently, it wasn't increasing fast enough to catch up with the rest of the world. In fact, Africa's throughput in 2009 was comparable to Europe's 15 years ago, and PingER data suggested the gap would widen to 25 years by 2020.

Happily, throughput has grown dramatically since 2009, putting Africa just 14 years behind Europe. If growth continues at the current rate, Africa may even catch up by 2030.

That's a big *if*, though. It remains to be seen whether this uptick in growth is just a short-lived aftereffect of the 2010 World Cup or whether new investments will sustain progress in the long run.

IF THE FUTURE of information technology in Africa seems uncertain, that's because it is. The 2010 World Cup undoubtedly set in motion big changes in the region. And as the continent continues to attract big investors and cutting-edge science research projects, its Internet performance will advance further still. For example, the Square Kilometre Array, a massive radio telescope being jointly built in South Africa and Australia, will haul more data between the two continents than travels through today's entire global Internet.

The reality, however, is that most Africans still face substantial, and often unpredictable, obstacles to Internet access, including poverty, political corruption, and the lack of basic services such as power and water. Even in the more stable countries, such as Angola and Kenya, that have built hefty broadband backbones, engineers have yet to find a tried-and-true way to extend cheap, dependable Internet service to rural communities.

As PingER data show, there is plenty of work to be done. My hope is that the technology will bring awareness to overlooked shortcomings in Africa's communications networks, as it did in Pakistan. And by expanding traditional cable networks as well as embracing "leapfrog" technologies such as Wi-Fi, low Earth orbit satellites, and mobile phones, providers will be able to deliver affordable broadband access to even the most remote corners of the continent. ■

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Prof. Yikai Su, Center for Opto-electronic Materials and Devices, Dept of Electronic Engineering,Shanghai Jiao Tong University, 800 Dong Chuan Rd, Shanghai 200240, China, Phone: +86 21 3420 7924, Fax: +86 21 3420 4371
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Responsibilities include research and teaching in the field of planning and operation of electrical power grids with a high content of distributed generation from renewable energies.

The new professor is expected to research in several of the following areas:

- Grid integration of power from renewable energies
- Modeling of electricity generation
- Control methods and operation of intelligent distribution grids (Smart Grids), virtual power plants, demand side management
- Use of information technology for efficient electrical power generation, transmission and distribution

Applicants are expected to have excellent scientific skills in at least two of the above mentioned technical areas as well as didactic qualifications. A successful career in industry, power utilities or research organizations will be appreciated.

This call for application is subject to approval by the Ministry of Science, Research and the Arts of Baden-Württemberg. The requirements for employment listed in § 47 and § 50 Baden-Württemberg university law apply.

Written applications including a CV, a teaching record and a list of publications should be sent no later than **04.02.2013** to the Dean of the Faculty 5 (Dekan der Fakultät 5, Universität Stuttgart, Pfaffenwaldring 47, 70550 Stuttgart, Germany) or via e-mail to: bewerbung-nee@f-iei.uni-stuttgart.de.

The University of Stuttgart has established a Dual Career Program to offer assistance to partners of those moving to Stuttgart. For more information please visit the web-page under: http://www.uni-stuttgart.de/dual-career/

The University of Stuttgart is an equal opportunity employer. Applications of women are strongly encouraged. Severely challenged persons will be given preference in case of equal qualifications.

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University of Glasgow

College of Science and Engineering
School of Computing Science

SINGAPORE INSTITUTE OF TECHNOLOGY

Assistant/Associate Professors in Computing Science

Assistant Professor, Salary Range SGD 75,000 - 125,000 — Ref: 003202
Associate Professor, Salary Range SGD 100,000 - 150,000 — Ref: 003204

The University of Glasgow, in partnership with the Singapore Institute of Technology, are seeking two highly motivated and capable members of academic staff to deliver assigned courses from the BSc (Honours) Computing Science curriculum of the University of Glasgow, from September 2013. Preference will be given to candidates with experience of teaching in Human-Computer Interaction or Computer Systems.

Join us and become part of this prestigious partnership working collaboratively with colleagues from both institutions to ensure the success of this exciting new venture.

Based on the campus of Republic Polytechnic in Singapore you will also undertake research of international standard.

Informal enquiries may be made to: Professor Joseph Sventek, Head of School
Telephone: + 44 141 330 8078 Email: Joseph.Sventek@glasgow.ac.uk

Apply online at www.glasgow.ac.uk/jobs

Closing date: 28th February 2013.

Interviews will be held in the Singapore Institute of Technology the week of 25 March 2013. Applicants will be notified of whether or not they will be invited for interview by 8 March 2013.

The University is committed to equality of opportunity in employment.
The University of Glasgow, charity number SC004401.
UGlasgow Singapore Pte Ltd. Wholly owned subsidiary company of the University of Glasgow.

POSITIVE ABOUT DISABLED PEOPLE

www.glasgow.ac.uk

Boston, MA

Northeastern University

PROFESSOR AND CHAIR

College of Engineering

Northeastern University College of Engineering invites applications and nominations for the position of Chair of the Electrical and Computer Engineering Department. The department is a large, successful and growing academic enterprise that includes 47 full-time faculty with over $13 million in annual research funding, over 450 MS and Ph.D. students and more than 400 undergraduates. The department hosts several federally-funded research centers in diverse fields including sensing and imaging, energy transmission, microwave materials and information assurance. The department is committed to innovative curricular development at all levels and has a top-ranked cooperative education program.

Qualifications:
A doctoral degree in Electrical and Computer Engineering or a closely related field is required. Previous experience managing a federally-funded research group or center, or similar significant administrative experience, is desirable.

Applicants should submit a detailed Curriculum Vitae, three professional references and a strategic vision statement. To apply, visit: **http://apptrkr.com/299357**

For more information contact: Prof. Miriam Leeser; Email: mel@coe.neu.edu; Phone: 617-373-3814.

EOE

NANYANG TECHNOLOGICAL UNIVERSITY | NUS National University of Singapore | SUTD SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

TEMASEK RESEARCH FELLOWSHIP (TRF)

A globally connected cosmopolitan city, Singapore provides a supportive environment for a vibrant research culture. Its universities Nanyang Technological University (NTU), National University of Singapore (NUS) and Singapore University of Technology and Design (SUTD) invite outstanding young researchers to apply for the prestigious TRF awards.

Under the TRF scheme, selected young researchers with a PhD degree have an opportunity to conduct and lead defence-related research. It offers:

- A 3-year research grant of up to S$1 million commensurate with the scope of work, with an option to extend for another 3 years
- Postdoctoral or tenure-track appointment (eligibility for tenure-track will be determined by the university)
- Attractive and competitive remuneration

Fellows may lead, conduct research and publish in these areas:

- Advanced Materials for Aerospace Applications
- Bio-mimetic Aerodynamics
- Cognitive Science and Neuroengineering
- Cyber Security
- High Power Laser Diode
- High Speed High Voltage Switching Devices

For more information and application procedure, please visit:

NTU –http://www3.ntu.edu.sg/trf/index_trf.html
NUS –http://www.nus.edu.sg/dpr/funding/trf.html
SUTD –http://www.sutd.edu.sg/trf

Closing date: 15 March 2013 (Friday)

Shortlisted candidates will be invited to Singapore to present their research plans, meet local researchers and identify potential collaborators in July 2013.

NAZARBAYEV UNIVERSITY

Faculty positions: Robotics and Computer Science

School of Science and Technology
Nazarbayev University
Astana, Kazakhstan

Nazarbayev University is seeking highly-qualified faculty at all ranks (assistant, associate, full professor) to join its rapidly growing undergraduate and graduate programs in the School of Science & Technology. NU was launched in 2010 as the premier national university of Kazakhstan, based on the Western model, with English-language instruction, partnering with some of the most recognized international universities including University of Cambridge, Carnegie Mellon University, University of Wisconsin, University College London, University of Pennsylvania, University of Pittsburgh, and Duke University.

Full-time faculty positions are open in the Departments of Robotics and Computer Science. 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.

Position responsibilities include: a teaching load of two courses (on average) per semester, establishment of an independent research program, program guidance and leadership (for senior positions), student advising and supervision, and general service to the department and the university.

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.

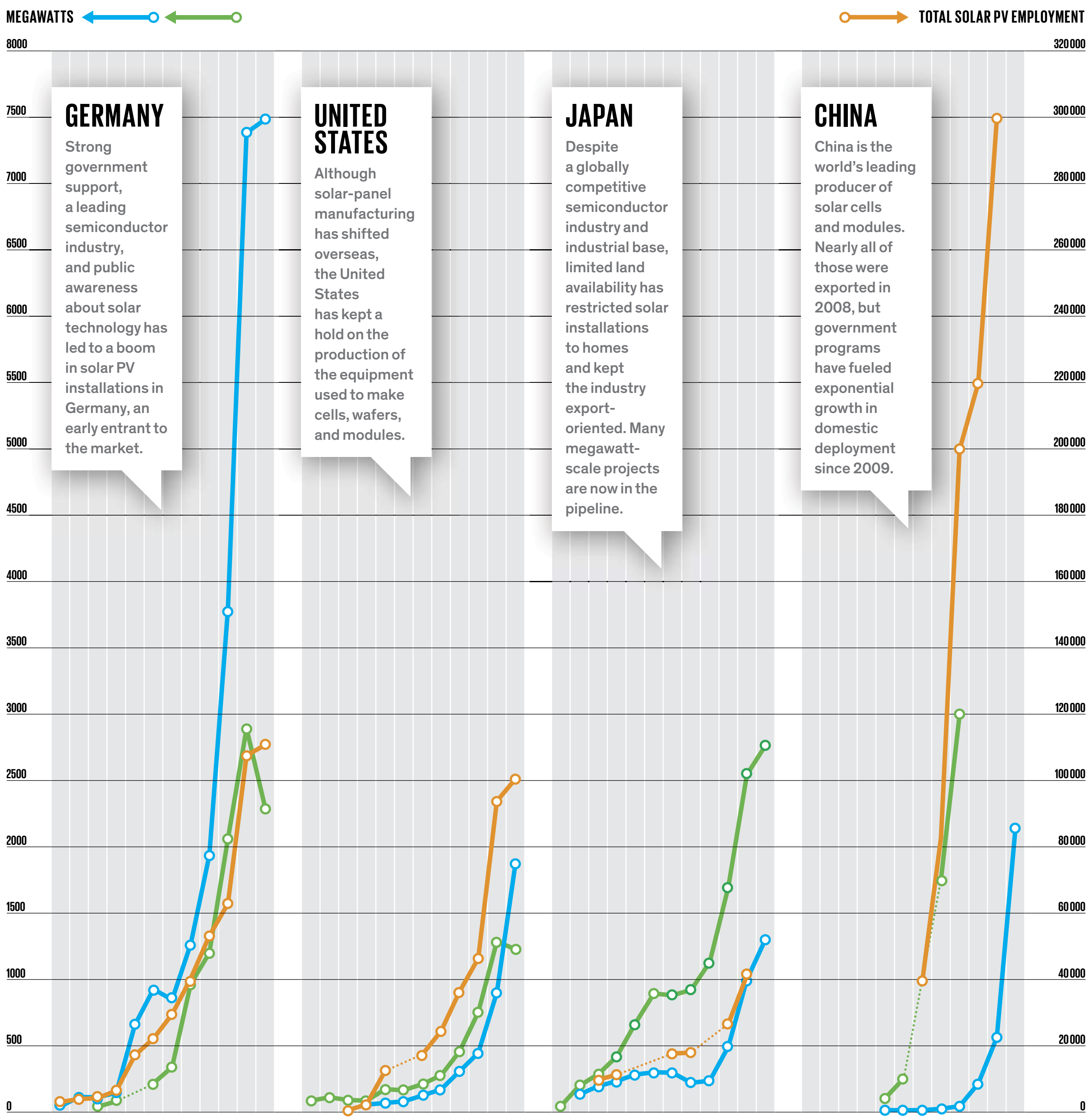
To Apply: applicants should send a detailed CV, including qualifications, experience, and list of publications to sst@nu.edu.kz. Interested parties are encouraged to submit their applications no later than **March 15th 2013**.

DATAFLOW_

SUNNY JOB GROWTH
GREEN ENERGY GENERATES EMPLOYMENT

Forget the environment. Is the renewable energy industry delivering on its promise to create jobs? Yes, according to a report by the World Resources Institute (WRI), in Washington, D.C. The WRI examined the solar photovoltaic and wind industries in countries that are leaders in renewables. • The message is clear, says one of the report's coauthors, Priya Barua: Comprehensive, targeted policies in these countries are spurring clean energy investments, which are creating jobs. • While most green employment debates center on manufacturing, Barua says data from the United States and Japan indicate that over 65 percent of jobs are actually created outside of manufacturing in such areas as R&D, system design, and installation. —PRACHI PATEL

Annual solar PV installed capacity (MW)
Annual PV module production (MW)
Total solar PV employment
Lapse in data availability



SOURCE: "DELIVERING ON THE CLEAN ENERGY ECONOMY," WORLD RESOURCES INSTITUTE

INFOGRAPHIC BY Carl DeTorres