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THE U.S. GOVERNMENT WANTS TO PROSECUTE **GARY McKINNON** FOR HACKING THOUSANDS OF CLASSIFIED COMPUTERS. THERE'S JUST ONE PROBLEM: **HE'S A CAUSE CÉLÈBRE IN THE UNITED KINGDOM**

DID AUTISM MAKE HIM DO IT?

WHY THE TOPOLOGICAL INSULATOR IS THE **STRANGEST NEW DEVICE** SINCE THE MEMRISTOR

JAVA'S BRILLIANT BUT **SHORT-LIVED PREDECESSOR**

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The U.S. government says Gary McKinnon is a dangerous hacker who broke into military networks and threatened national security. McKinnon's supporters say he's a misunderstood martyr with autism. *By David Kushner*

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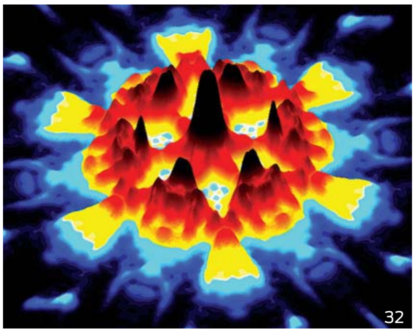

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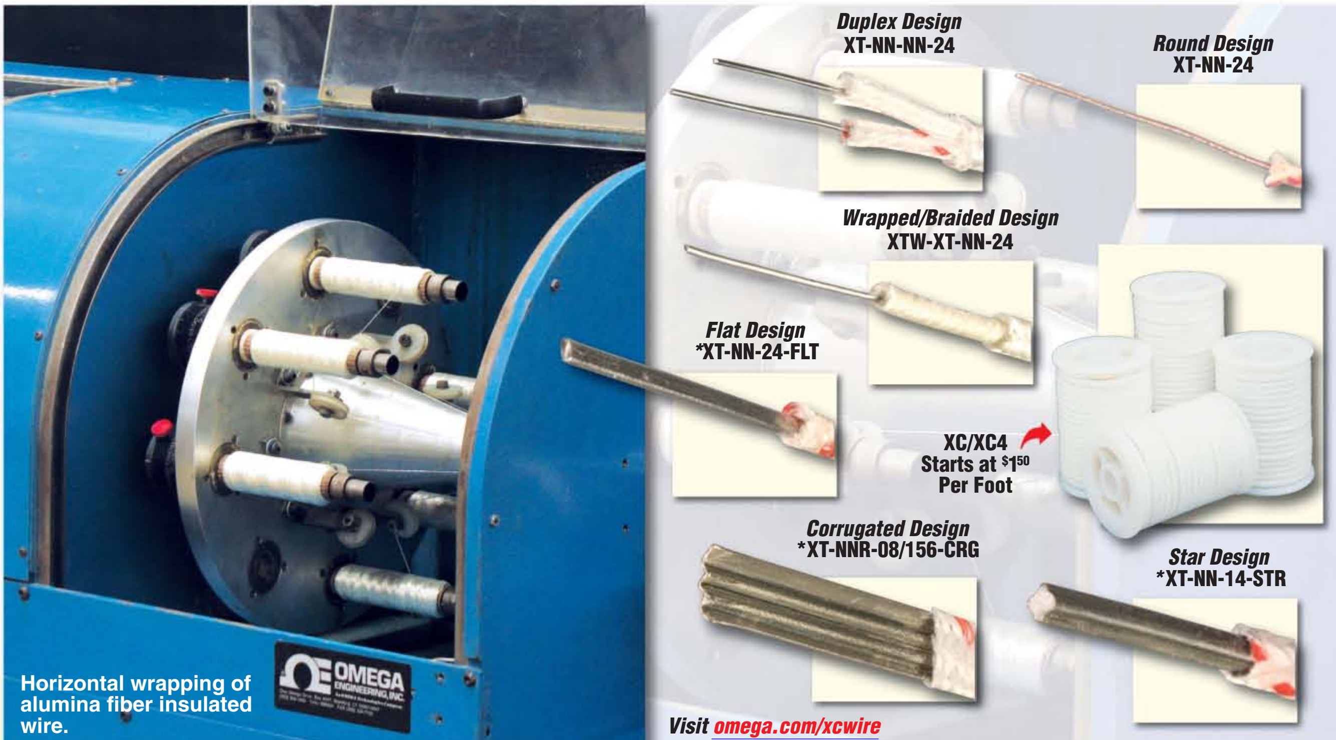

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The Art of the Hack

During the 1982 Harvard–Yale football game, a black weather balloon 2 meters in diameter, with "MIT" in large white letters, emerged from midfield and exploded, showering the field in talcum powder. Check out *IEEE Spectrum*'s ongoing series of stories—including a slideshow of MIT hacks, based on the new version of the book *Nightwork*—about hacking, for good, for evil, and for just plain fun.

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CLOUD COMPUTING STANDARDS
As part of its Cloud Computing Initiative, IEEE is developing two standards for how cloud applications and services would interact and be portable across clouds.

PEARL STREET STATION HONORED
In 1882, Thomas A. Edison launched the modern electric utility industry with the opening of the Pearl Street Station in New York City. IEEE recently recognized the achievement with a Milestone in Electrical Engineering and Computing.

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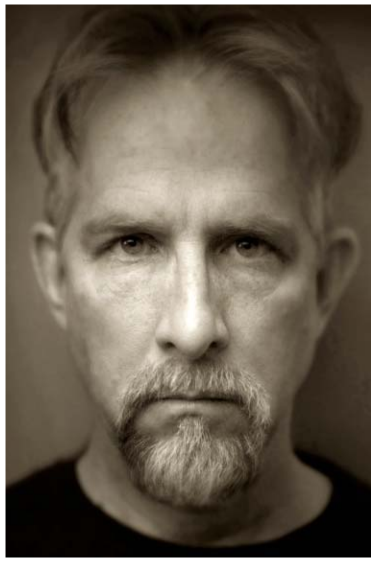
back story

Casting for Complexity



MATT MAHURIN, illustrator of this issue's cover, sees magazine art directors as if they were casting agents for movies—they define the essence of a subject and choose the right artist to bring it to life.

With a subject like Gary McKinnon, *IEEE Spectrum*'s senior art director, Mark Montgomery, needed an artist who could portray complexity. Mahurin's work—at once dark and shocking, transcendent, funny, and grotesque—filled the bill. "He really gets into the psychology of his subjects," Montgomery says.

Mahurin, who cites Salvador Dalí, Norman Rockwell, and his friend Tom Waits as influences, was fascinated by McKinnon's story [see "The Autism Defense" in this issue]. "On one level, he walks the line between a criminal and victim," he says, "and on another level, he's a very troubled, sad character." He's exactly the kind of subject that Mahurin likes to take on. "I don't like black and white or anything too on the nose," he says. He wanted to make the portrayal of McKinnon a "mix of menace and sadness."

Besides illustrating magazines, Mahurin films documentaries, directs music videos, shoots photos, and paints canvases. His résumé includes covers for *Time* magazine—he did his first when he was 23—an MTV music video award for R.E.M.'s "Orange Crush," and more than a few memorable celebrity encounters.

He has seen the inside of Cher's bedroom and shared a Jacuzzi with Joni Mitchell. He's smoked a cigar with Lou Reed, had lunch with Metallica, and played tennis with Peter Gabriel. "That guy's ruthless on the court," he says.

Mahurin attributes his success to his own personal drive. In the mid-1980s, on assignment for *Rolling Stone* to shoot part of a U2 concert, he talked his way backstage and convinced the band's lead guitarist, The Edge, to take a look at some of his photos. The rock star bought a picture on the spot and, with the other members of the band, invited Mahurin to tag along for the rest of their tour. Afterward, Mahurin ended up designing the cover of one of their EPs, *Wide Awake in America*.

"In creative fields you have to be so self-motivated and so self-driven," Mahurin says. "It harkens back to my early dating days—I had to be a little pushy. But I wanted to be adorable about it." ❑

MATT MAHURIN

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, The Data is in *IEEE Spectrum*, Vol. 48, no. 7 (INT), July 2011, p. 60, or in *IEEE Spectrum*, Vol. 48, no. 7 (NA), July 2011, p. 68.

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contributors

TOM GIBSON is a consulting mechanical engineer specializing in renewable energy and recycling and a freelance writer covering technology. He's also an avid mountain biker and laments that he didn't get to try out the electricity-producing exercise bicycles he describes in "Turning Sweat Into Watts" [p. 46]. "But I did take apart my wife's StairMaster to see how typical exercise machines work," he says.

DAVID KUSHNER, an *IEEE Spectrum* contributing editor, covers the extraordinary case of Gary McKinnon, who's been accused of hacking into U.S. military and NASA computers. In "The Autism Defense" [p. 26], Kushner explains that McKinnon's lawyers have asked for leniency based on his diagnosis of Asperger's, a form of autism. "The article explores whatever link there may be between engineering abilities and Asperger's," says Kushner. "But I don't mean to suggest that if you have Asperger's, you're going to be a cybercriminal."

JOSH McKIBLE, a.k.a. mckibillo, did the illustrations for "Turning Sweat Into Watts" [p. 46]. His art is inspired by instruction manuals, both the really good ones and the really bad. "The thing that started me on this path was in-flight safety cards," he says. "They're so badly done, and they're about such a terrifying moment—the disconnect between the style of information and what you need just blew my mind." Originally from New York City, he now lives in Japan.

WILLIAM W. McMILLAN, who heads the computer science department at Eastern Michigan University, recalls being impressed by the UCSD p-System when he first came across the operating system in the late 1970s. "In many ways we went backward when we went to MS-DOS," he says. He recently decided to explore the history of the p-System, in part because it is conceptually similar to Java. To his surprise, he found evidence linking the two, as he describes in "The Soul of the Virtual Machine" [p. 38].

JOEL E. MOORE, author of "Topological Insulators" [p. 32], received his Ph.D. in physics from MIT and has been on the faculty of the University of California, Berkeley, since 2002. He was part of the collaboration that first predicted topological insulators in three dimensions. Moore says he's been "amazed" by the subsequent flood of experimental work in the field, which among other things confirmed the materials' existence in 2008. "The hard work of many other people connected our mathematical conjecturing to reality," he says.

JONATHAN B. SPIRA, who wrote about Internet TV for this issue [p. 20], is the founder of Basex, a think tank that ponders business productivity. In his book *Overload!*, he describes information overload as "death by a million paper cuts." The book has a curious effect on people: "On flights, people start pouring their hearts out, telling me how overloaded they are. I become a personal therapist," he says.

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NATIONAL INSTRUMENTS

More Cyberattacks or Just More Media Attention?

THIS HAS been a banner year for high-profile cybersecurity disasters, with no letup in sight. So far, there have been 251 data breaches—a record-setting pace. Sony's PlayStation and Entertainment Networks have been repeatedly hacked, with more than 100 million of the company's user accounts compromised and its online gaming halted for several weeks. A security breach at the Internet marketing company Epsilon resulted in millions of customers' e-mail addresses being taken from about 100 major corporations, including Disney Destinations in the United States and Dell in Australia. A cyberintrusion at Nonghyup, South Korea's main agricultural cooperative, crashed its banking systems for a week and kept 30 million customers from accessing their accounts. Blackmailers broke into the financial systems of Hyundai Capital, accessed the personal details of 1.75 million customers, and then demanded US $460 000 to keep the purloined information from being made public.

Then there are the targeted attacks against security vendors like Comodo and RSA. A hacker fooled a Comodo group affiliate into issuing Internet SSL certificates to some of the world's largest websites, including Google, Microsoft, Mozilla, Skype, and Yahoo. A partially successful attack against RSA's two-factor authentication security product SecurID, which is used by 30 000 organizations around the world, has led to "significant and tenacious" attacks against a number of major U.S. defense contractors, including the world's largest, Lockheed Martin.

There have also been successful cyberintrusions against government computer systems in Australia, Canada, France, and the United States. The Canadian break-in caused its treasury board as well as its department of finance to restrict access to the Internet for months, while the breach in Australia apparently allowed access to the personal e-mail accounts of several top officials, possibly even that of Prime Minister Julia Gillard.

So are the number of cyberattacks increasing, or are we just more aware of them? The answer seems to be both.

Data from organizations monitoring cybersecurity activity indicate significant increases in the frequency of attacks over the past five years—especially against government IT systems. Last year British government systems saw more than 650 attempted intrusions per day, while U.S. government systems received 15 000 suspicious hits per day, or about one every 6 seconds. A typical bank like Citigroup, which was breached in May, sees an average of about 30 000 probes a day.

While the cyberattack trend is going up, the impact of these attacks has also increased. This year's cyberintrusions are international in nature, long lasting, and economically material, generating prolonged media attention.

Furthermore, tens of millions of individuals around the world have been made personally aware of many of the attacks. Millions of people, for example, received apologetic e-mails from the companies affected by the Epsilon breach; I received five such e-mails in one week. Social media like Twitter have increased the reporting of these cyberincidents.

No one should be surprised by the number or the magnitude of successful cyberintrusions. The Internet was not built with security in mind.

Regrettably, most IT systems and applications that connect to the Internet were not developed with security in mind either, nor has there been much incentive to do so. A recent survey of cloud-computing providers by the Ponemon Institute, for example, indicates that the majority of providers don't believe security is their responsibility, nor do they see their customers demanding security or being willing to pay for it.

It's important to keep the relative risk in perspective. It will be a while before a cybersecurity incident by itself will be able to create damage on a par with a Joplin, Mo., tornado, let alone a Fukushima tsunami. Right now, as Howard Schmidt, the White House cybersecurity coordinator, says, cyberattacks are just the risk of doing business. Sadly, only when the risk of cyberattacks becomes unaffordable will cybersecurity be taken seriously. —ROBERT N. CHARETTE

ROBERT N. CHARETTE, an IEEE Spectrum *contributing editor, is a self-described "risk ecologist" who investigates the impact of the changing concept of risk on technology and societal development.*

This article is adapted from several posts he wrote for Spectrum*'s Risk Factor blog.*

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update

Supercomputers Predict a Stormy Hurricane Season

New simulations will show not just how many storms will strike, but where

THE CLOUDS spat out an intermittent drizzle of rain—the kind of halfhearted shower that no one could have predicted—as Jane Lubchenco, administrator of the U.S. National Oceanic and Atmospheric Administration, stood outside NOAA's Satellite Operations Facility and revealed her organization's predictions for the 2011 North American hurricane season.

"NOAA's forecast team is calling for an above-normal season this year," Lubchenco intoned. This hurricane season, which began on 1 June and runs through November, is likely to produce 6 to 10 hurricanes in the Atlantic basin, Lubchenco said. Of those storms, 3 to 6 are expected to become major hurricanes, rated Category 3 or above, with sustained winds stronger than 178 kilometers per hour.

If you live near the North Atlantic, pay attention, because NOAA is on a forecast winning streak. Last year's outlook was "amazingly accurate," said Lubchenco. NOAA predicted 8 to 14 hurricanes, with 3 to 7 biggies, and that's what North America got: 5 major hurricanes out of 12 overall.

Soon, thanks to an ongoing upgrade to the agency's supercomputing software, future forecasts could show not just how many storms will form but also where they'll strike.

Forecasts start at the Satellite Operations Facility, in Suitland, Md., where the antenna dishes

SCOREBOARD: Data from NOAA's Satellite Operations Facility is the starting point for the agency's hurricane forecasts.
PHOTO: ELIZA STRICKLAND

update

SATELLITE SEEKERS: NOAA tracks 15 satellites for its forecasts.
PHOTO: ELIZA STRICKLAND

that stud the roof pull down more than 16 gigabytes of environmental data every day from a fleet of 15 polar-orbiting and geosynchronous weather satellites. The cloud systems and ocean currents that whirl beneath the satellites' visual and infrared cameras are the raw material for NOAA's climate models, explains Gerry Bell, who serves as lead forecaster for the hurricane season at NOAA's Climate Prediction Center. "Knowing what the West African monsoon is doing is critical," Bell says, "because that's ultimately where a lot of these storm systems originate. And there's very little climate data coming out of West Africa." The satellites also provide hard-to-obtain data about El Niño and La Niña weather patterns, which form over the equatorial Pacific Ocean, Bell says.

Each April, all the current satellite data about both atmospheric and ocean conditions are fed into a computer model of the global climate, as the starting point for a season-long simulation. The simulation runs on an IBM Power6 mainframe computer, which can reach speeds of 69.7 teraflops. Jae Schemm, who oversees the models at the Climate Prediction Center, says that it takes about three days of compute time to complete one eight-month run of the season. This year, Schemm's team finished 19 simulation runs to provide information for NOAA's hurricane outlook. "In these model runs, we actually see tropical storms developing in the Atlantic basin and track their progress," Schemm says. "That's how we come up with the number of storms we expect for the season." The storm counts produced by NOAA's model runs are then combined with statistical estimates based on climate conditions to produce the final hurricane outlook.

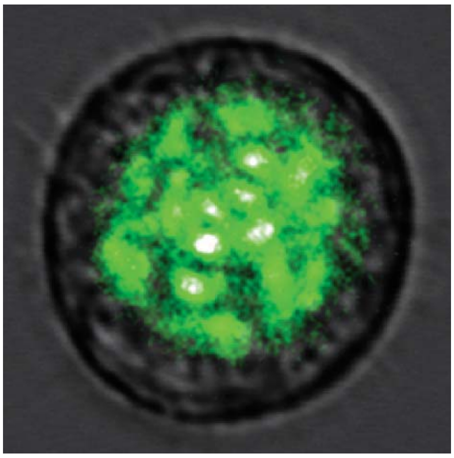
As sophisticated as NOAA's current climate model is, it's getting an upgrade. On 30 March, the newest version of the model began test runs. In the previous version, the atmospheric and ocean models exchanged information once every "day" of the simulation. In the new version, every time the ocean model takes a step forward—every 30 minutes of each simulated day—the two models will swap data, says Schemm.

The new model will also begin to incorporate some of the subtleties of global warming. It will include information about melting sea ice near the poles, as well as the annual readings of carbon dioxide concentrations in the atmosphere. "In the previous version we just used a fixed concentration of CO_2, but it's changing every year," explains Schemm.

The new software wasn't used for this year's hurricane outlook, and it won't be used next year, either; it must first be tested on historical climate conditions dating back to 1981. But when the simulation goes into service, Bell says, NOAA forecasters can take the next step: attempting to predict not just how many dangerous storms the Atlantic Ocean will give birth to in a season but also how many will make landfall and which stretches of coastline should prepare for a blow. "We don't do that now," says Bell, "but with the continued development of these models, it's now at least a possibility."

—Eliza Strickland

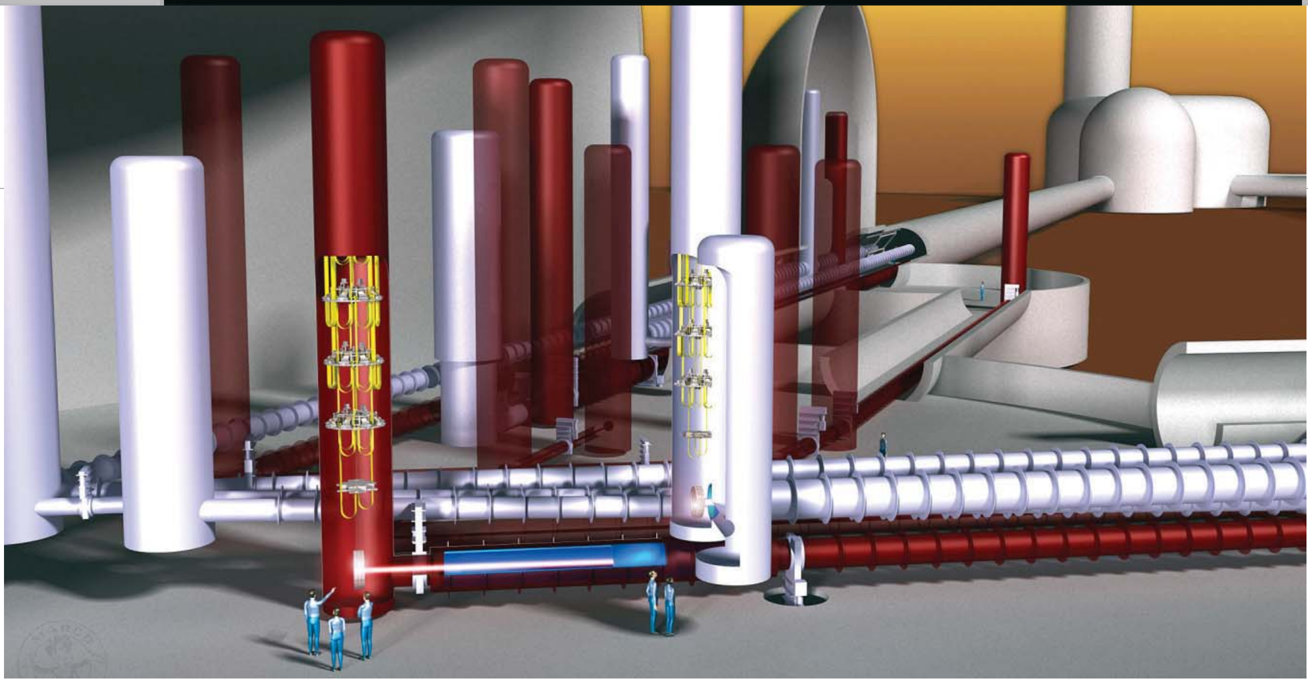
A version of this article appeared on our website in June as "Satellites and Supercomputers Say 6 to 10 Hurricanes Coming."



HARVARD MEDICAL SCHOOL

A Living Laser

Scientists at Harvard Medical School say they've turned a human cell into a green laser. The scientists genetically engineered the cell to produce a green-glowing jellyfish protein and then placed the cell between two reflectors. In this setup the cell acts as the laser's gain medium, typically a semiconductor or a purified gas. When pumped with a brief burst of blue light, the proteins fluoresced, generating light that bounced back and forth between the reflectors, gaining more energy with each pass through the cell. What good is a lasing cell? The Harvard scientists think it could make it easier to see the effects of genetic and other experiments inside animals or even aid in the examination of subcellular structures.



GRAND DESIGN: The Einstein Telescope will be buried 150 meters down and measure 10 kilometers on a side.

The Einstein Telescope

Planning a bigger, badder gravitational-wave detector

THE UNIVERSE is filled with spectacular events that we don't understand. Right now, a star is going supernova, but we don't know what the inside looks like; two neutron stars are spiraling toward each other, but we don't know what the collision will look like. And a black hole is swallowing another black hole, but we don't know how they're shaped.

What makes these phenomena so hard to fathom is that the electromagnetic messages they send out are limited. But those messages aren't their only signals: According to Einstein's general theory of relativity, such events should create powerful waves of gravity—ripples in the curvature of space-time that alternately stretch and compress everything in their path.

Although scientists have been trying for decades, they have yet to directly observe these waves. Scientists have already built the first generation of large-scale gravity-wave detectors, and a second generation, expected to make the very first observation later this decade, is under construction. But a team of European scientists and engineers is already thinking beyond the second-generation instruments: On 19 May, they presented a design for an €800 million device 10 times as sensitive and capable of seeing 1000 times the volume of space. They call it the Einstein Telescope.

"We're hoping to see new things, things that no one knows of," says Harald Lück, deputy scientific coordinator of the Einstein Telescope design study. "As astronomers in the field like to say, with gravity waves, we could see the dark side of the universe."

The instrument, which won't start making observations until 2025 at the earliest, isn't a telescope in the Galilean sense; it and its predecessors are laser interferometers that measure tiny distortions—much smaller than the diameter of a proton—in the length of tubes several kilometers long. The telescope design includes three detectors, each consisting of two 10-kilometer-long arms—more than twice the size of the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO), the largest second-generation gravitational interferometer. The arms will lie parallel to Earth's surface and connect at a 60-degree angle, with a laser, a beam splitter, and a photodetector situated at the junction. A beam will shoot into the splitter, and each resulting half will do laps up and down tubes in one of the arms, bouncing back and forth off mirrors.

In the absence of a detectable gravitational wave, the split beams will recombine and cancel each other out, shining no light on the photodetector. But when a strong wave—from, say, a swirling binary star—hits the instrument, one of the arms will contract minutely and the other will expand, then vice versa, shifting the phases of the split beams and allowing a signal to pass through.

In making the Einstein Telescope supremely sensitive, the challenge lies in canceling out noise. To detect a broader range of cosmic events, the telescope is designed to pick up gravitational waves of 3 to 10 hertz, lower in frequency than those picked up by second-generation models. As a result, earthquakes, tides, and even human activity could really throw the device off. To avoid some of this interference, the detectors will be built away from the coast and 150 meters underground, according to Lück. But even in a ditch, the instrument would be so sensitive that the random motion of the mirrors' molecules would get in the way. The solution is to chill the mirrors to an icy 10 kelvins.

Over the next few years, Lück's team will research and develop the telescope's high-tech subsystems, look for potential sites, and flesh out the design further. But before the project can move forward, second-generation systems need to show that they can detect gravitational waves. "Without that last experimental proof, such a big investment will not be made," Lück says.

According to Joseph Giaime, head of LIGO's Louisiana detector, that could still be five or six years away. —RITCHIE S. KING

ILLUSTRATION: MARCO KRAAN/NIKHEF/ET SCIENCE TEAM

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update

Flywheels Keep the Grid in Tune

Spinning masses face off against big batteries in the half-billion-dollar market for grid stability

IF YOU think twirling the mass of a family car hundreds of times a second is an unlikely way to keep power grids humming at perfect pitch, think again. Flywheel developer Beacon Power Corp., based in Tyngsboro, Mass., is already making money that way in Stephentown, N.Y., where it operates more than 160 1150-kilogram magnetically levitated flywheel motor-generators. These machines continuously accelerate and decelerate to balance electrical supply and demand and thus keep New York state's grid tuned to 60 hertz.

AC frequency fluctuates from second to second as generators turn on and off and consumer demand varies. When demand exceeds supply, the extra load slows down power plant turbines, thus depressing frequency. Meanwhile, the turbines accelerate whenever supply is in excess. Frequency regulators add or remove power to restore balance.

Beacon's flywheels can regulate frequency with superior speed relative to the dominant method today—throttling power generators up and down. And grid operators are changing outdated rules to favor faster-acting regulators, including flywheels and grid-scale batteries. The prize: priority access to a frequency regulation market worth US $495 million in the United States last year and growing with the expansion of ever-varying wind and solar power.

The task of frequency regulation has never been a great fit for power plants. Generators operate most efficiently when held steady at high output, so holding capacity in reserve and ramping output up and down increases emissions and fuel costs. And because many power plants take a minute or longer to respond to dispatch signals, much of their contribution is ineffectual or sometimes even counterproductive.

"By the time they get around to responding, things are already going in another direction," explains David Hawkins, a senior principal consultant for the Netherlands-based energy consulting firm Kema, who until last year was lead engineer for integrating renewable energy at California's grid operator.

In contrast, the Stephentown flywheels can switch from full output to full absorption in just a few seconds. Such flexibility means the flywheels can deliver at least twice as much frequency regulation from each megawatt of capacity as a typical natural-gas-fired power plant while cutting carbon emissions in half, according to Hawkins.

Such performance should translate into steady revenues under today's frequency regulation rules—and considerably more as the rules shift. Generally speaking, the independent system operators (ISOs) that manage regional power markets buy frequency regulation services by renting control over tranches of generation capacity. Because they respond more quickly, flywheels are likely to be called upon ahead of power plants. Judith Judson, Beacon's vice president for asset management and market development, says that's been Beacon's experience at Stephentown, which started up in January with 8 megawatts of flywheel capacity and was scheduled to reach its full 20-MW design capacity in June.

Judson says that revenues could triple under an order proposed by the U.S. Federal Energy Regulatory Commission in February that requires ISOs to compensate frequency regulators based on their performance. "If you set aside 20 MW and you're called upon a lot because you can respond fast, you're paid more," says Judson. New England's ISO already has such a "mileage" system under pilot rules, expected to be formalized this year. PJM Interconnection, the grid operator for the mid-Atlantic states, also announced plans for performance pricing, and Beacon is readying a $50 million, 20-MW plant

REVVED UP: A flywheel generator is lowered for high-speed tests.
PHOTO: BEACON POWER CORP.

$338 billion to $476 billion Cost of building a U.S. smart grid, according to a report by the Electric Power Research Institute.

update

in Hazel Township, Pa., to take advantage of it.

One challenge will be competition from battery-based frequency regulators, which are cheaper per megawatt to install. Several battery systems are testing the market, including a 20-MW frequency regulating facility that Arlington, Va.–based power firm AES is building in Johnson City, N.Y. The $22 million plant uses lithium batteries from A123 Systems.

If facilities such as

DRUMROLL, PLEASE: A carbon-fiber flywheel is removed from a coating chamber. PHOTO: BEACON POWER CORP.

AES's succeed, frequency regulation could soon be lithium batteries' biggest market. Sanyo Electric, the market leader in lithium-ion battery production, bets that frequency regulation and other grid applications will account for two-fifths of lithium battery sales in 2020. Electric vehicles and consumer electronics will split the rest of the $60 billion market, Sanyo predicts.

Beacon, for its part, bets that the apparent cost advantage of batteries will literally erode with time, as constant cycling degrades their capacity. The company says its flywheels in Massachusetts experience the equivalent of 6000 cycles of full charge and discharge or more per year and are designed to withstand that abuse for 20 years, with minimal maintenance or performance degradation.

Kema's Hawkins agrees that batteries will lose their edge over flywheels under that level of use. "A battery really doesn't like to be totally charged and discharged," says Hawkins, "whereas flywheels can handle a pretty severe duty cycle."

But he says that another threat looms, one that could eviscerate the market for frequency regulation: millions of electric vehicles. Plugged in to the grid, they could respond to frequency deviations at the local level.

Pacific Northwest National Laboratory, a unit of the U.S. Department of Energy, proved a similar concept a few years ago, showing that electric water heaters and dryers could correct frequency dips by temporarily turning off their heating elements. In March, PNNL licensed the concept to Texas-based semiconductor start-up Encryptor, which hopes to make chips for appliances.

So in the future, the frequency regulator could be you. —Peter Fairley

Superconductor Logic Goes Low-Power

Energy-efficient superconducting circuits could be key to future supercomputers

Transistor-based semiconductors have dominated the computing industry since its start. But a much more exotic, transistor-less option has long been lurking in the wings. Superconducting circuits, which boast resistance-less wires and ultrafast switches, can perform the tasks that silicon-based systems do in a fraction of the time.

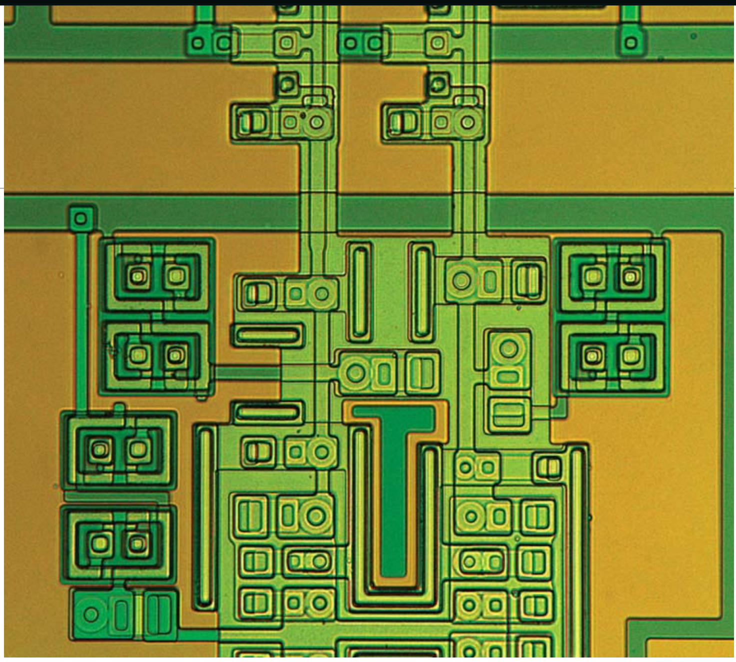
Now new logic designs are emerging that suggest superconducting processors could be not only faster but also tens or even hundreds of times as energy efficient as their CMOS cousins. And these processors could provide a much-needed path to the next generation of supercomputers, proponents say.

This next generation, called exaflop computers, would be capable of executing a quintillion (10^{18}) operations per second, about 1000 times as many as existing computers can. Once thought to be just 5 or 10 years away, they now seem nearly impossible. A recent estimate suggests that an exascale supercomputer built using CMOS technology would consume some 500 megawatts—the output of a modest nuclear power plant. "What everybody's shooting for is to be able to overturn [that] result," says Erik DeBenedictis of Sandia National Laboratories, in Albuquerque. "Now there's a glimmer of light that it might happen."

Superconducting circuits have long been an attractive option for ultrafast processors. Chilled down to a few degrees above absolute zero, superconducting logic gates can perform operations in picoseconds with less than a microwatt of power. Simple superconducting logic circuits have been shown to operate at speeds of up to 770 gigahertz.

But the technology has been slow to make its way into complex circuits. Since the early 1990s, most superconducting circuits have been built using a design called rapid single-flux quantum (RSFQ) logic, which relays bits of information in the form of short voltage pulses carried by tiny, speeding vortices of current.

RSFQ has been used to build a number of specialized devices needed for high-throughput and numerically intensive applications, such as communications receivers and signal processing. But the design consumes too



COLD LOGIC: Hypres's new logic could make superconductors superefficient.
PHOTO: HYPRES

much power to be scaled up to processors that could compete with CMOS chips in high-end computers. To distribute current among gates, RSFQ relies on a network of bias resistors that can consume 10 times as much power as superconducting logic uses for computation.

In an attempt to build circuits that are more energy friendly, Quentin Herr and his colleagues at Northrop Grumman Systems Corp., in Baltimore, took aim at these resistors. "We ended up changing almost all the characteristics of the logic," Herr says.

To eliminate the bias resistors, the team members switched the power source of the circuit from DC to AC, which allowed them to replace the resistors with transformers that don't draw power when the circuit isn't performing computations. As in RSFQ, logic pulses stream through the circuit, where they are blocked, passed, or rerouted by sandwiches of superconducting material and insulator called Josephson junctions. The presence or absence of a pulse within a given time period determines whether a bit is a 0 or a 1.

By using AC, the team could send pulses in pairs of opposite voltage—the inverted humps of a sine wave. While the first pulse was used for computation, the second was used to reset the circuit. This allowed the Northrop Grumman engineers to simplify the design, cutting down on the number of Josephson junctions needed in each logic gate. The results of tests on some basic logic circuits were published online in May in the *Journal of Applied Physics*.

Herr reckons that circuits that use the new design, which his team calls reciprocal quantum logic (RQL), will require 1/300th the power of the most advanced CMOS circuits. Crucially, that estimate includes the power needed to cool the circuits to superconducting temperatures.

Others are betting that improvements to RSFQ logic could produce similar gains in energy efficiency. At Hypres, in Elmsford, N.Y., Oleg Mukhanov and his colleagues have found they could eliminate a huge power loss by simply replacing bias resistors with sets of inductors and Josephson junctions. The team published its approach in June in *IEEE Transactions on Applied Superconductivity*.

Hypres does not have circuits that can be directly compared to Northrop Grumman's, but the company anticipates that its design will rival RQL in power efficiency. Mukhanov says he expects the new RSFQ design will also be easier to scale up to more complex circuits than the RQL scheme, which requires tighter timing tolerances.

But RQL could still be the better technology when it comes to energy consumption, says Mikhail Dorojevets, an associate professor of electrical and computer engineering at Stony Brook University, in New York. He is working on a project funded by the U.S. Army Research Office to evaluate how well the two new logic families perform when scaled up to simulated 32-bit processors.

Dorojevets says these designs help build a foundation for ultralow-power superconducting processors that could potentially work at speeds of 20 to 50 GHz. But it will be quite some time before such processors make their way into supercomputing facilities. While superconducting logic is making strides, other processor components—particularly memory—require a lot more development.

Limited resources could be the biggest obstacle to superconducting supercomputers. Today's machines take advantage of a large industry that has invested many billions of dollars developing chips for other purposes. "If you choose to build an exascale system starting from scratch with an unproven device technology, you must pay for everything. I don't see an entity or agency with the money and the incentive," says Thomas Theis, a program manager at IBM's Thomas J. Watson Research Center, in Yorktown Heights, N.Y.

"It's a very big and aggressive goal," Herr admits. "But revolutions usually don't happen all at once."

—Rachel Courtland

news brief

Apple Up on Top

New rankings by market analysts at IHS iSuppli, in El Segundo, Calif., show that in 2010, for the first time, Apple bought more chips than any other technology manufacturer. The company edged out Hewlett-Packard and Samsung Electronics, buying US $17.5 billion worth last year. According to iSuppli, Apple will leave those two in the dust in 2011, spending $22.4 billion on semiconductors, $7.5 billion more than HP. Apple is buying mostly NAND flash memory for use in iPhones, iPads, and the like. HP, by contrast, spends most of its budget on chips for desktops, notebooks, and servers, according to the analysts.

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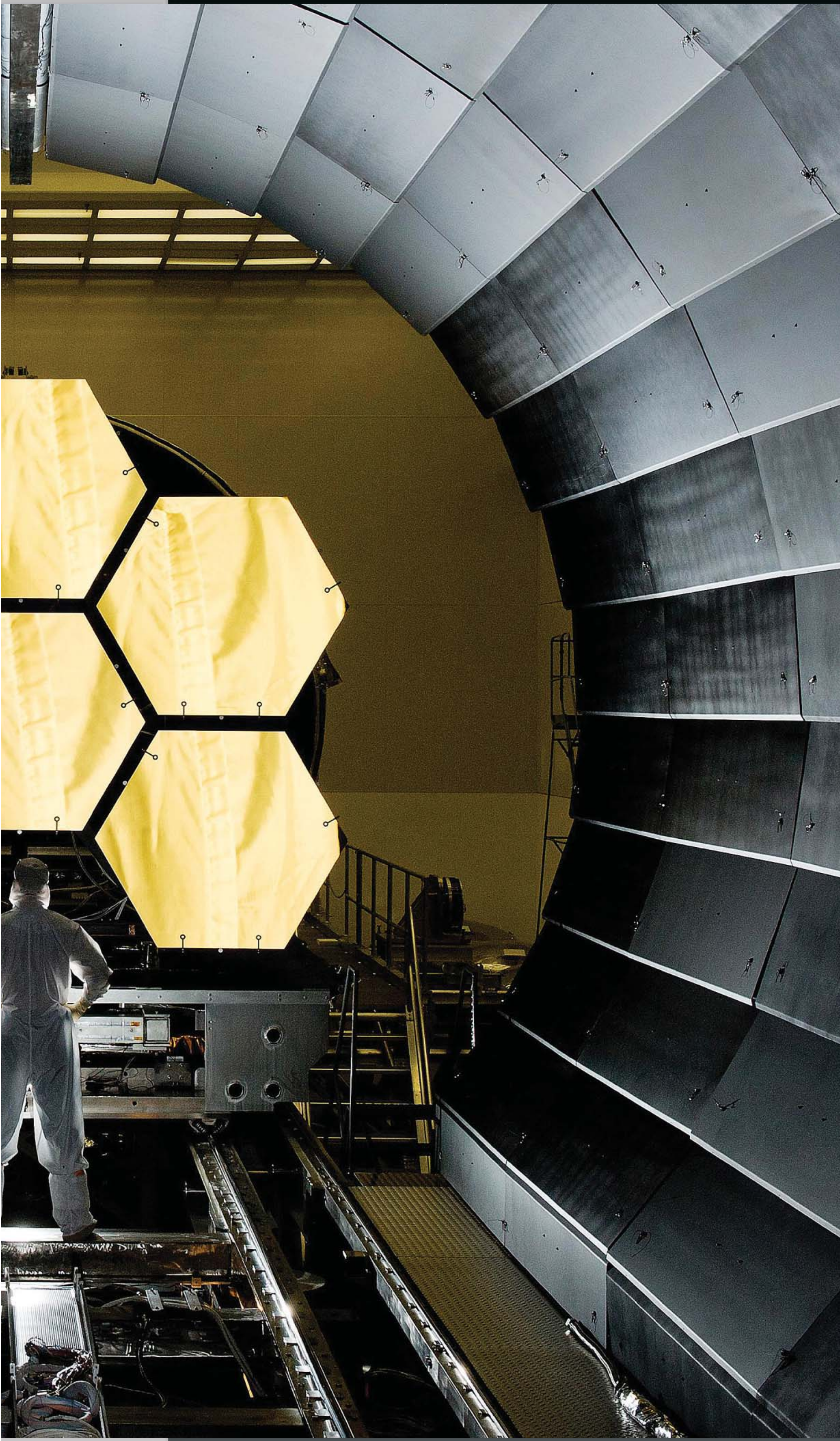

the big picture

REFLECTING BACK IN TIME

These six hexagons represent one-third of the primary mirror array that will allow the James Webb Space Telescope to help scientists create a more detailed timeline of the universe. The aim is to bring the period from the formation of the first stars to the emergence of our solar system into sharper focus. The foldable 6.5-meter-diameter mirror will be unfurled once the telescope reaches its eventual orbit, 1.5 million kilometers away. (Webb's predecessor, the Hubble Space Telescope, resided in an orbit 570 km from Earth.) Here, the mirror's pieces are being prepped for cryogenic testing at NASA's Marshall Space Flight Center in Huntsville, Ala., to ensure that they can maintain the proper temperature for sensing minute bits of energy amid celestial clutter.

PHOTO: DAVID HIGGINBOTHAM/NASA/REDUX

tools & toys

	PRODUCT	WHAT IT DOES	QUALITY
	**Apple iPad** http://apple.com/ipad; US $500 and up	Tablet computer; plays Internet-based content, iTunes, and content from some cable networks	1024 by 768 pixels (9.7-inch display); up to 1080p with Apple Digital AV Adapter
	**Apple TV** http://apple.com/appletv; $100	Stand-alone device that links broadband connection to television	AirPlay to AppleTV, 720p; with Digital AV adapter, 1080p
	**Logitech Revue with Google TV** http://logitech.com/en-us/smartTV/revue; $300	Stand-alone device that links broadband connection to television	1080p; HDMI output
	**Roku** http://roku.com; $60–$100	Gateway to Hulu, Netflix, and other Web-based services	1080p; HDMI output

Internet TV: Almost Ready for Prime Time

One television watcher's search for the perfect IPTV service

IN THE 1970s, growing up in New York City, one of my favorite toys was a Norelco shortwave radio, a present from my father, who was born in Austria. I would tune in to radio broadcasts from the BBC World Service and the Deutsche Welle. It was a thrill to listen to broadcasts from far-off lands.

In 2001, I came across the modern-day equivalent—an Internet radio player. I soon found I had little use for terrestrial radio, although I still watched television the traditional way, via my cable provider.

I first started looking around for alternatives to cable TV in 2005, when German TV, a premium cable channel available in the United States, was shut down. Surely my favorite German shows must be available online, no? A Web search revealed the answer: a firm maybe. I was able to find some shows on the Internet, but not others. While I kept my cable service, I also uncovered a wealth of online television content from around the world.

Of course, I wanted to watch these programs on my shiny new 42-inch Sony flat-screen TV, so I connected an old IBM ThinkPad directly to the Sony. Picture quality ranged from poor to okay if viewed at a distance. It was like the thrill of listening to shortwave radio all over again.

In 2007 Steve Jobs introduced Apple TV, claiming it was "like a DVD player for the 21st century." This was an exaggeration, but Apple TV proved a good way to view my collection of digital movies. Soon, Apple had made deals with the major movie studios to rent films through iTunes. Between the ThinkPad and Apple TV, I found myself watching more and more on TV without turning on the cable box.

I soon added boxes from Roku and Vudu, which allowed me to push more movies and TV shows onto my TV. (Vudu no longer makes a dedicated box, but it still offers a premium online movie service; Roku currently offers a variety of services, including movies from Amazon.com and Netflix as well as Hulu.)

Then, in 2008, I came across the WhereverTV receiver, a small set-top box that provides a sophisticated channel guide that cuts across dozens of countries and thousands of broadcasters. Now we were talking! The only strikes against the WhereverTV box were the quality of the image—which depends on the sender of the video—and the lack of Flash support.

In 2009 Verizon FiOS, a fiber-optic broadband, telephone, and video service, came to my New York City neighborhood. FiOS was faster, which greatly improved the quality of online video. But I still lacked a good way to marry my flat screen to the Internet, because more

	PRODUCT	WHAT IT DOES	QUALITY
	**Vudu** http://vudu.com; $2 per movie for two nights	Promises the largest selection of HD movies and availability same day as DVD release	1080p; HDMI output
	**WhereverTV** http://wherever.tv; Free	Browser-based channel guide to thousands of TV stations on the Internet, sortable by country, language, and genre	Browser and PC dependent
	**WhereverTV receiver** http://wherever.tv; $200	Tiny box provides WhereverTV channel guide that links broadband connection to television	Composite and S-Video
	**Zediva** http://zediva.com; $2 for 14 days; 10 movies for $10	Works with any browser, including Google TV. Promises new movies same day as DVD release	480p, but quality will be browser and PC dependent

and more broadcasters were relying on Flash, something the WhereverTV box couldn't handle. So even with FiOS, I was still watching a lot of shows on a large computer display.

My dream of a better IPTV set-top box was finally realized in 2010 with the Logitech Revue with Google TV. While Google bills Google TV as a tool to search the Web, I view it and its Chrome browser as a window to Internet television.

Today I can watch almost anything found on a website on my television. The major exceptions are the U.S. television networks, which currently block Google TV. The networks' stance is inconsistent, because they make many of these shows accessible via Hulu, a content aggregator owned by News Corp. (Fox), Walt Disney (ABC), and NBC Universal, among others. Were I to connect my laptop to the TV in place of the Logitech box, I could easily watch the same shows on Hulu or often the networks' own websites on the very same screen. Google TV itself blocks nothing, so a viewer can watch pirated copies of the very same shows on such websites as Surfthechannel.com.

The paid version of Hulu—Hulu Plus—charges US $7.99 per month for unlimited access to 40 current shows, plus thousands of older programs (I found the original episodes of "Adam-12," for example). CBS News has a free app that provides video programming from the "CBS Evening News," "Face the Nation," "48 Hours," and "Sunday Morning," among others. If I want to watch "60 Minutes" on the iPad, however, I have to buy the app for a one-time fee of $4.99. ABC similarly offers an iPad app with a mix of free programs and others that can be bought on iTunes.

In some cases, I can take movies and videos playing on the iPad and stream them to Apple TV, and thence to my TV screen, using Apple AirPlay. Sadly, this doesn't work with Hulu and the broadcast network apps.

Now the iPad is becoming a battleground that may determine how television programs are viewed in the United States. Both Time Warner and Cablevision Systems Corp. have in recent months released apps that allow their subscribers to view content on the iPad itself, in essence turning the iPad into a TV. The Time Warner app has multiple limitations—you have to subscribe to television and broadband services, and the app functions only in your home. Even so, some content owners have objected, forcing Time Warner to remove content. The Cablevision app tries to mirror the content that would be available on the subscriber's TV set and doesn't require the subscriber to have Cablevision's broadband service.

All these tricks still aren't enough to free us from traditional TV, but the bonds will continue to loosen. For example, Mark Cavicchia, president of WhereverTV, told me that the company plans to transform its guide so that it works with Roku and Boxee (a freeware home theater program) and, eventually, Google TV.

However, there's a downside to cutting the cord—it could starve programmers and thus induce them to take their content off-line. "More than 50 percent of a programmer's income is derived from cable subscriptions. As people cut ties to the cable companies, the programmers will naturally reduce what can be accessed for free," says Larry Thaler, president of Positive Flux, a consultancy that helps media companies deal with the changing landscape.

My experience with IPTV may not be the norm, but it most likely portends the future of the industry. Companies such as Apple and Google have seemingly cracked the code in terms of selling apps and entertainment. Netflix, whose postal delivery of DVD rentals killed off Blockbuster, has already figured out that the secret to movie rentals is to stream them over the Net, seemingly via any and all devices, including many Blu-ray players. Can other content be far behind? Meanwhile, a new company, Zediva, "rents" DVDs over the Net, giving online viewers access to movies the same day they are released on DVD.

For now, Internet TV augments rather than displaces the traditional television experience. I believe we'll come to see a hybrid model, in which we'll buy fewer premium channels and services from traditional TV providers and go online for more and more of our entertainment. The only problem that remains is how we'll pay for it.

Watching TV via the Net is an adventure. Just as I had to adjust the aerial of my Norelco shortwave radio, sometimes I have to reboot the Revue Google TV box or reload a Web page half a dozen times in order to get good "reception." But it's worth the trouble.

—Jonathan B. Spira


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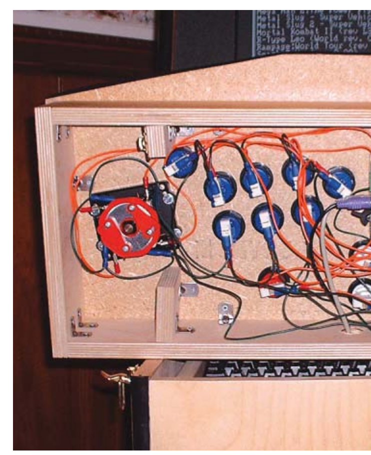

BUILDING YOUR OWN ARCADE GAME

The ultimate home video-game experience needs a big cabinet and flashing lights

First there were pinball machines. Then came video games, with far more computing and graphics power than you could get at home. Two generations later, home PCs have so far outstripped those early arcade machines that emulating old game programs in software is trivial.

And yet devotees still prefer arcade machines, much as audiophiles cling to their turntables. What sets the arcade experience apart today is what isn't electronic: big solid joysticks, trackballs that look like they could take a blow from a baseball bat and keep spinning, and refrigerator-size cabinets blazing with decorative lights and gaudy artwork.

John St. Clair, whose day job is working for a school district in Georgia, says it all started with *Space Invaders*. It was 1997, and he and a friend were reminiscing. "On a whim," he recalls, "I went online to see if I could find a version of it for the PC. I stumbled across MAME"—for multiple arcade machine emulator—"and was instantly hooked. After playing for a while with keyboard and mouse, I ran across a thread on a forum called Dave's Video Game Classics, where a few guys

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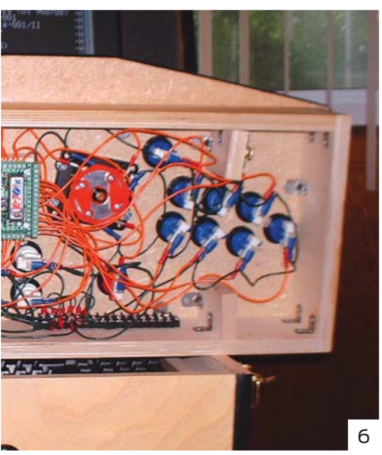

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Project Arcade
Build Your Own Arcade Machine, 2nd ed.
By John St. Clair; Wiley, 2011; 552 pp. (paperback); US $30; ISBN 978-0-470-89153-7
http://www.projectarcade.com

CABINET MAKER: Alexandre Denault, a video-game developer in the mobile industry, built his own arcade machine as a special project with his father. His starting point was *Project Arcade*, "at the time, the best (and only) book on this topic." He documents the process on his blog, Beshiros @ Home (http://www.beshiros.com/arcade), including the cabinet construction and assembly (see photos 1, 3, 4, 5), the addition of the keyboard encoder (2), and the wiring (6).

PHOTOS: ALEXANDRE DENAULT

were talking about how great it would be to use real arcade controls with the computer."

One thing led to another, and pretty soon St. Clair was running a website that aggregated virtually all the information retrogamers might want to build their own arcade controllers. Then, while writing the first edition of *Project Arcade*, he built his first arcade machine.

Over the years, he says, a small but hardy industry has sprung up to serve those who want to build replicas of old machines. In the early days, for example, people would build their own spinner knobs from VCR motors, but now there are sources for optically encoded spinners and trackballs, joysticks, and the ubiquitous heavy-duty buttons. And of course, customized keyboard encoders—the vital components that convert encoder pulses and button presses into the signals that a PC emulating an arcade game can understand—are widely available as well.

The one hardware item that's getting harder and harder for retrogamers to find is the display. CRTs are rapidly becoming extinct, and no one makes large LED displays with the relatively tiny pixel counts that characterized early-generation arcade machines. If your favorite game (*Battlezone*, for example) ran on a vector monitor, you're even further out of luck. St. Clair says you'll have to find and refurbish an old vector monitor, order a PC-compatible vector generator from Zektor, and then wait until there are enough customers on the company's waiting list to finance one last production run. Or you could just go with a regular display and let the PC do vector-to-raster conversion on the fly.

If you decide to build an arcade of your own by following the instructions in St. Clair's book (and on his website), be prepared to spend a few months doing it. You'll need to get all the parts, design the front panel (or re-create one from your favorite game), then build the cabinet, paint it in the bright colors of your choice, and finally put everything together. Most of the tools are fairly straightforward, if a little specialized, like the 1⅛-inch drill bit for push-button mounting holes and the special low-profile wrench for turning the nuts that hold the button body in place.

And what do you do once you've built one? You build another. St. Clair has two cabinets in play as of this writing, and his dream—if he can't find and restore the originals—is to build home versions of *Discs of Tron* (in which the player stands inside a booth with lights and speakers that give that "derezzed" feeling) and *Star Wars*, complete with cockpit and adjustable seat.

—Paul Wallich

ALIX MINDE/GETTY IMAGES

geek life

WEIGHT LOSS SURGERY AS SYSTEMS ENGINEERING

Plastic surgeon Gary Horndeski's new surgical techniques decrease appetite

Gary Horndeski was early into his plastic surgery practice in the 1990s when he noticed that his tummy tuck patients continued to lose excess fat and maintain their new weights without trying. He says he might have shrugged it off as a coincidence if it weren't for his engineering background. Instead, he speculated that a person's satiety could be controlled by additional intra-abdominal pressure.

Horndeski—an aspiring electrical engineer before detouring into medicine in 1972 to avoid the Vietnam War draft—had studied mechanics at Case Western Reserve University, in Cleveland, which was one of the first universities in the country with a biomedical engineering department. "I'm the product of that marriage," he says.

As a medical student, he would often build Heathkits for fun, once prophetically putting together a digital scale. Two decades later, he found himself looking at the human stomach with the eye of an engineer. It wasn't the first time Horndeski had adapted engineering techniques to plastic surgery—he had already applied some civil engineering concepts to breast reduction procedures.

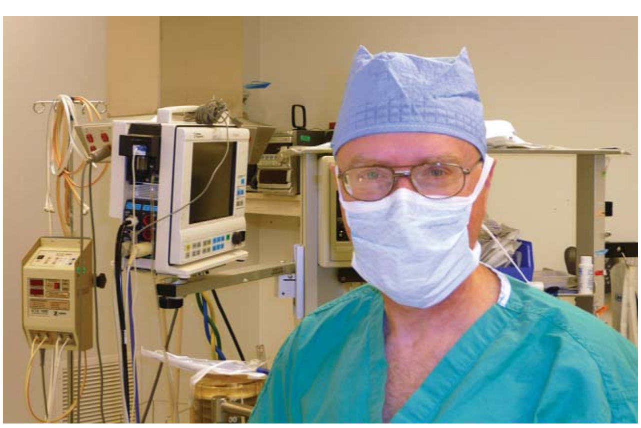
Horndeski's epiphany about weight loss came about because he had already reengineered the standard tummy tuck. The established procedure involves suturing the left and right sides of abdominal fascia—an elastic tissue that overlies the muscles and weakens with pregnancy and age—to each other. Instead, Horndeski reinforces the fascia with synthetic mesh. It's a technique he'd picked up from doing abdominal reconstruction surgery during a fellowship at M.D. Anderson Cancer Center, in Houston, from 1988 to 1989. His patients with the plastic mesh seemed to have no trouble keeping their weight down; also, the mesh increased external pressure on the stomach. Was there a connection? Horndeski hypothesized that receptors within the stomach wall respond to that pressure just as those in a normal eater tell the brain to stop eating when the stomach is full.

"The brain has a reference level of what's considered full and compares it to the information sent by the stomach receptors," says Horndeski. Recipients of a standard tummy tuck put weight back on because the abdominal wall is not reinforced. Patients with the mesh reinforcement feel too full to eat for several days after surgery. "Once they lose intra-abdominal fat, the pressure on the stomach eases and then they can eat again," he says. "A girdle won't work, because it doesn't provide nearly the same pressure as mesh."

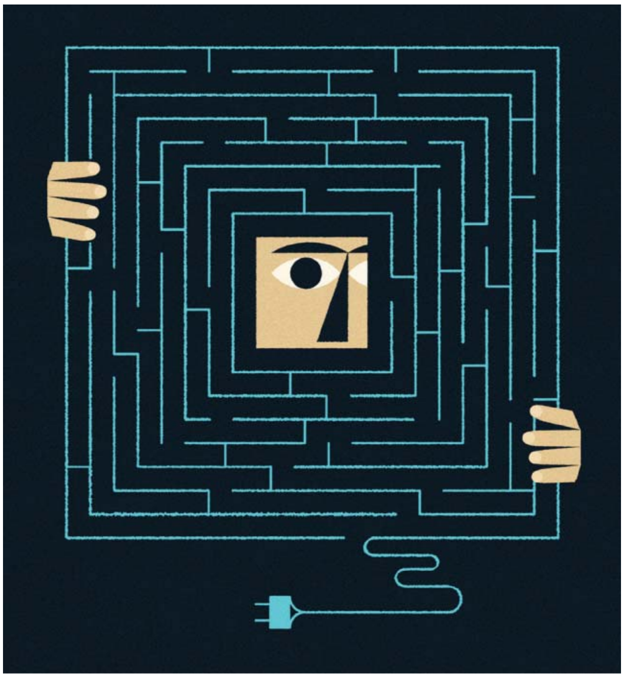
In preparation for a 2010 paper on the subject, Horndeski discovered supporting animal and human studies from the 1940s to 2007. He worked out a block diagram that models the human weight feedback system as an operational amplifier (an integrated circuit that amplifies output) and then quantified "how food amplifies your weight and how that information is fed back into the brain."

Horndeski has a patent pending on the concept and is waiting for the hospital where he operates, Angleton Danbury Medical Center, in Texas, to approve this surgery for weight loss. "I was able to connect the dots between stomach pressure and weight loss in large part because of my backgrounds in math and system theory, which is unusual for a plastic surgeon," he says.

—Susan Karlin



WEIGHT STATES: Plastic surgeon Gary Horndeski has reengineered the tummy tuck. *PHOTO: ELISA GONZALEZ* reflections BY ROBERT W. LUCKY



GREG MABLY

In Research, the Problem Is the Problem

A problem well stated is a problem half solved.
—Inventor Charles Franklin Kettering (1876–1958)

WE'RE ALL fairly good at problem solving. That's the skill we were taught and endlessly drilled on at school. Once we have a problem, we know how to turn the crank and get a solution. Ah, but finding a problem—there's the rub.

Everyone knows that finding a good problem is the key to research, yet no one teaches us how to do that. Engineering education is based on the presumption that there exists a predefined problem worthy of a solution. If only it were so!

After many years of managing research, I'm still not sure how to find good problems. Often I discovered that good problems were obvious only in retrospect, and even then I was sometimes proved wrong years later. Nonetheless, I did observe that there were some people who regularly found good problems, while others never seemed to be working along fruitful paths. So there must be something to be said about ways to go about this.

Internet pioneer Craig Partridge recently sent around a list of open research problems in communications and networking, as well as a set of criteria for what constitutes a good problem. He offers some sensible guidelines for choosing research problems, such as having a reasonable expectation of results, believing that someone will care about your results and that others will be able to build upon them, and ensuring that the problem is indeed open and underexplored.

All of this is easier said than done, however. Given any prospective problem, a search may reveal a plethora of previous work, but much of it will be hard to retrieve. On the other hand, if there is little or no previous work, maybe there's a reason no one is interested in this problem. You need something in between. Moreover, even in defining the problem you need to see a way in, the germ of some solution, and a possible escape path to a lesser result, like the runaway truck ramps on steep downhill highways.

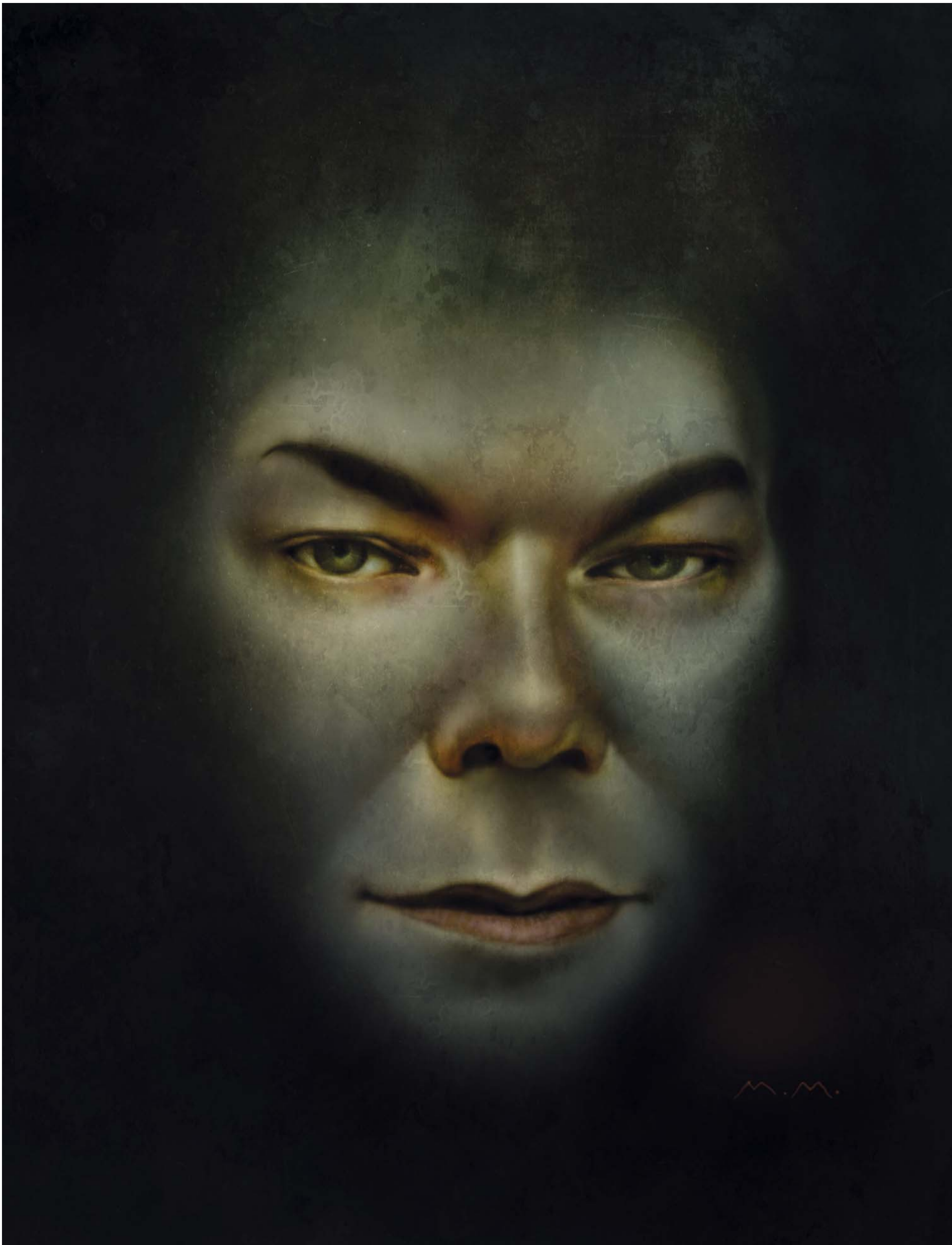
Timing is critical. If a good problem area is opened up, everyone rushes in, and soon there are diminishing returns. On unimportant problems, this same herd behavior leads to a self-approving circle of papers on a subject of little practical significance. Real progress usually comes from a succession of incremental and progressive results, as opposed to those that feature only variations on a problem's theme.

At Bell Labs, the mathematician Richard Hamming used to divide his fellow researchers into two groups: those who worked behind closed doors and those whose doors were always open. The closed-door people were more focused and worked harder to produce good immediate results, but they failed in the long term.

Today I think we can take the open or closed door as a metaphor for researchers who are actively connected and those who are not. And just as there may be a right amount of networking, there may also be a right amount of reading, as opposed to writing. Hamming observed that some people spent all their time in the library but never produced any original results, while others wrote furiously but were relatively ignorant of the relevant literature.

Hamming, who shared an office with Claude Shannon and knew many famous scientists and engineers, also remarked on what he saw as a "Nobel Prize effect," where having once achieved a famous result, a researcher felt that he or she could work only on great problems, consequently never doing great work again. From small-problem acorns, great trees of research grow.

Like a lot of things in life, it helps to be in the right place at the right time. Sometimes all the good and well-intentioned advice in the world won't help you avoid working on a dead-end problem. I know—I've been there, done that. ❑



the *autism* *defense*

GARY MCKINNON HACKED THOUSANDS OF GOVERNMENT COMPUTERS. HIS LAWYERS SAY HIS AUTISM IS TO BLAME

by DAVID KUSHNER

A FEW MONTHS AFTER THE WORLD TRADE center attacks, a strange message appeared on a U.S. Army computer: "Your security system is crap," it read. "I am Solo. I will continue to disrupt at the highest levels."

Solo scanned thousands of U.S. government machines and discovered glaring security flaws in many of them. Between February 2001 and March 2002, Solo broke into almost a hundred PCs within the Army, Navy, Air Force, NASA, and the Department of Defense. He surfed around for months, copying files and passwords. At one point he brought down the U.S. Army's entire Washington, D.C., network, taking about 2000 computers out of service for three days. U.S. attorney Paul McNulty called his campaign "the biggest military computer hack of all time."

But despite his expertise, Solo didn't cover his tracks. He was soon traced to a small apartment in London. In March 2002, the United Kingdom's National Hi-Tech Crime Unit arrested Gary McKinnon, a quiet 36-year-old Scot with elfin features and Spock-like upswept eyebrows. He'd been a systems administrator, but he didn't have a job at the time of his arrest; he spent his days indulging his obsession with UFOs.

MATT MAHURIN

In fact, McKinnon claimed that UFOs were the reason for his hack. Convinced that the government was hiding alien antigravity devices and advanced energy technologies, he planned to find and release the information for the benefit of humanity. He said his intrusion was detected just as he was downloading a photo from NASA's Johnson Space Center of what he believed to be a UFO.

Despite the outlandishness of his claims, McKinnon now faces extradition to the United States under a controversial treaty that could land him in prison for years—and possibly for the rest of his life. The case has transformed McKinnon into a cause célèbre. Supporters have rallied outside Parliament with picket signs. There are "Free Gary" websites, T-shirts, posters. Rock star David Gilmour, the former guitarist for Pink Floyd, even recorded a benefit song in his honor.

Why the spectacle? McKinnon has been diagnosed with Asperger's syndrome, a form of autism. The range of conditions known as autism spectrum disorders currently affects 1 out of 110 American children, according to the U.S. Centers for Disease Control and Prevention. Researchers say that diagnoses of these problems are increasing faster than those of any other developmental disorder. Medical researchers still don't understand the cause and are nowhere near a cure.

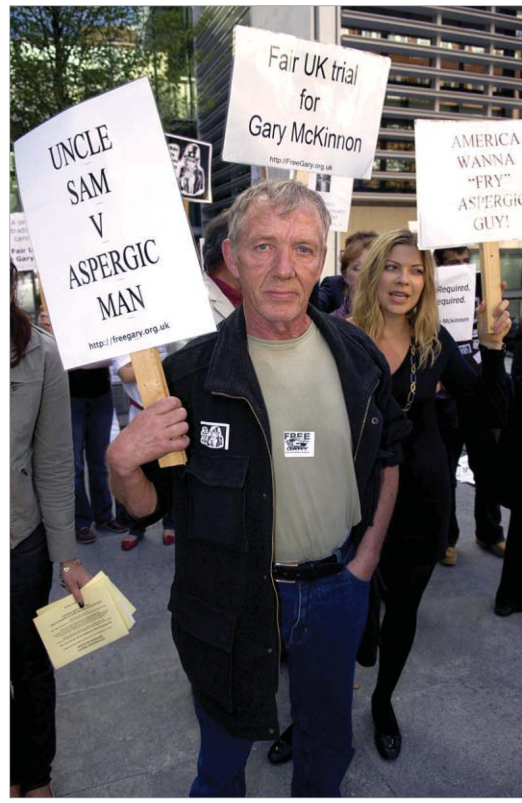
People with Asperger's are often highly intelligent, and many have an accomplished grasp of complex systems, causing researchers to study a possible link between autism and engineering. But Asperger's sufferers have severe difficulty reading social cues and grasping the impact of their often-obsessive behavior. "There have been an inordinate number of young men with Asperger's who have gotten in trouble with the law," says autism expert Rhea Paul of the Yale School of Medicine Child Study Center. "It's difficult for them to intuit moral decisions that may come more easily to others," she says. McKinnon's lawyers argue that his criminal behavior was a result of his disorder, and they have asked courts to judge him with leniency as a result.

Meanwhile, a debate is raging over the role of Asperger's in his crime. Former UK prime minister Gordon Brown is among those who have said that McKinnon deserves sympathy. Others believe the disorder does not merit a lesser sentence. "There is a need for stronger penalties for hackers," says Amit Yoran, former National Cyber Security Division director within the U.S. Department of Homeland Security. "Without consequences for people's actions, an entire underpinning of modern society is at risk."

McKinnon's case raises a new and provocative question: Could Asperger's become the insanity defense for the hackers of the digital age?

McKinnon had always been fascinated by outer space. A puckish, bright boy from Glasgow, he would ask his parents technical questions about the distance between planets and the scientific names of stars. "It was the kind of stuff a toddler didn't usually talk about," McKinnon's mother, Janis Sharp, tells *IEEE Spectrum*. "It was very unusual."

But McKinnon's differences went far beyond his obsession with astronomy. Whenever Sharp took him on a bus, the boy would shout uncontrollably. By the age of 10, he had grown fearful of the outdoors and spent hours in his room devouring books on space or listening to music. When Sharp, a musician recently divorced



CAUSE CÉLÈBRE: Gary McKinnon [top left] enters a London courthouse; his mother [top right] holds a card signed by well-wishers; his father [bottom right] participates in a rally; actress Trudie Styler [bottom center] stands by McKinnon's mother; supporters demonstrate in front of the UK Home Office [bottom left].

PHOTOS: CLOCKWISE FROM TOP LEFT: DANIEL BEREHULAK/GETTY IMAGES; PRESS ASSOCIATION/AP PHOTO (2); OLI SCARFF/GETTY IMAGES; CATE GILLON/GETTY IMAGES

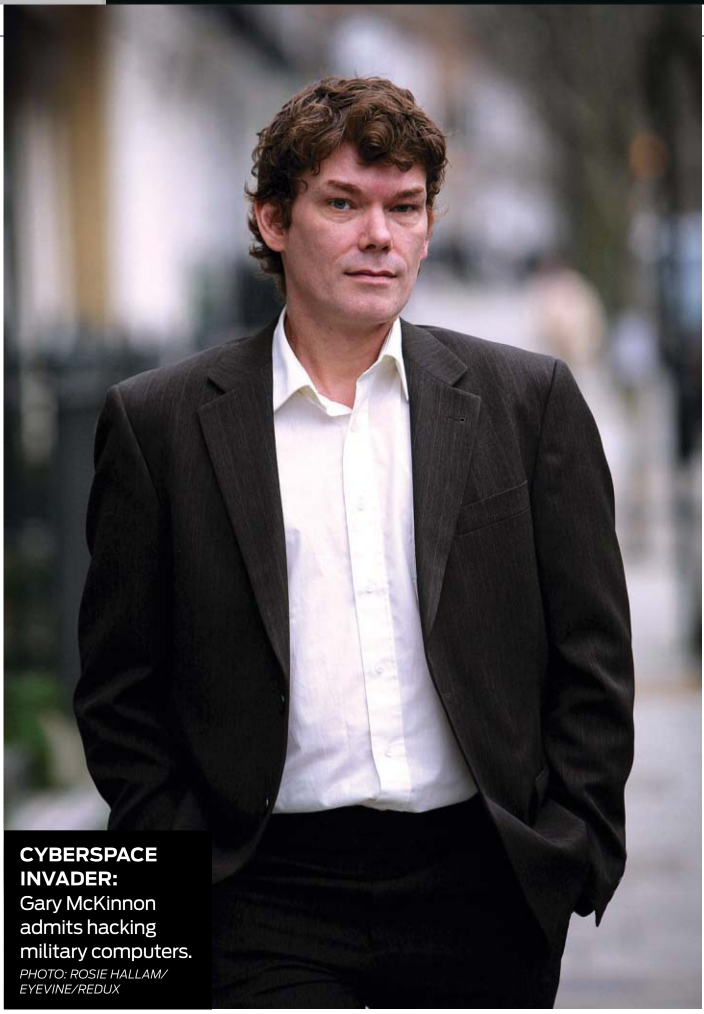
and living with Gary in London, begged him to join the neighborhood kids outside, McKinnon would plead, "Please don't make me go out to play." The boy was troubled, but his obsessions seemed to give him a sense of control and peace. Though not a naturally gifted musician, he spent hours at the piano teaching himself to play Beethoven's *Moonlight Sonata* and complicated Beatles songs. Sharp couldn't believe her ears. "We were knocked out," she says.

At age 14, he taught himself to code video games—set in outer space, of course—on his Atari computer. McKinnon joined the British UFO Research Association and found a community of like-minded space buffs. When he learned that his stepfather had grown up in Bonnybridge, an English town famous for UFO sightings, he grilled him for information, his mother recalls.

But while McKinnon dreamed of flying saucers, he struggled with everyday life on Earth. After dropping out of secondary school, he floated between jobs in computer technical support. The childhood fear of public transportation had grown even worse, and McKinnon suffered fainting spells when he had to ride the London Underground. Although he lived with his childhood sweetheart, a bright and amiable girl, he couldn't bear the thought of starting a family.

"How can I be responsible for a baby?" he asked his mother. As his relationship with his girlfriend waned, McKinnon grew increasingly despondent, losing his job and refusing help. His mother feared that his depression could lead to suicide. But McKinnon made a key discovery: the new world being created on the nascent Internet of the mid-1990s. "That's when he started looking online for information on aliens," Sharp says. "It was his escape."

AFTER READING *THE HACKER'S HANDBOOK*, the classic 1980s how-to book for computer hackers, McKinnon decided to do a bit of sleuthing himself. Late at night in his darkened bedroom he began trying out the book's



CYBERSPACE INVADER: Gary McKinnon admits hacking military computers.
PHOTO: ROSIE HALLAM/ EYEVINE/REDUX

suggested techniques, and in 2000 he decided to look for UFO evidence on the U.S. government's computer systems.

McKinnon put his powers of concentration to use, obsessively researching ways to break into the machines. Using the Perl programming language, he wrote a small script that he says allowed him to scan up to 65 000 machines for passwords in under 8 minutes. After dialing up the government systems, he ran the code and made an astonishing discovery: Many federal workers failed to change the default passwords on their computers. "I was amazed at the lack of security," he later told the *Daily Mail*.

On these unsecure machines, McKinnon installed a software program called RemotelyAnywhere, which allows remote access and control of computers over the Internet. McKinnon could then browse through the machines at his leisure and transfer or delete files. Because he was able to monitor all activity on the computers, he could log off the moment he saw anyone else logging on.

With his fixation overpowering him, McKinnon surfed through government computers from Fort Meade to NASA's Johnson Space Center in his quest for E.T. He claimed he had found a list of the U.S. Navy's "nonterrestrial officers," as well as a photo of a cigar-shaped UFO studded with geodesic domes (a photo he couldn't save, he said, because it was in Java script). After a lifetime of obsessing about UFOs, he was now feeding his habit as never before. He was also savoring the thrill of the hack. "You end up lusting after more and more complex security measures," he told *The Guardian* in 2005. "It was like a game. I loved computer games. I still do. It was like a real game. It was addictive. Hugely addictive."

But the game finally ended. The U.S. Department of Justice hasn't publicly discussed how it became aware of McKinnon, but he believes his intrusion was detected when he logged onto a computer at the Johnson Space Center at the wrong time. He has said that his access to that computer was immediately cut off; he believes the government then discovered the RemotelyAnywhere software on the machine and traced its purchase to his e-mail address.

In March 2002, his mother's phone rang. "I've been arrested," McKinnon said. Sharp's throat constricted—what had her son gotten himself into? But McKinnon told her not to worry. The UK National Hi-Tech Crime Unit had arrested him under the Computer Misuse Act, McKinnon said, which carried a relatively benign sentence of six months' community service. "I don't need to get a lawyer," McKinnon assured his mother. But that statement would prove incredibly naive.

IN 2005 THE UNITED STATES moved to extradite McKinnon under an extradition treaty created after the attacks of September 11 to aid in the prosecution of suspected terrorists. The U.S. Department of Justice doesn't care about his bizarre motivations for the hack, and it claims that the damage he caused was severe. He is charged with causing over US $700 000 in damages ($5000 per machine) and deleting at least 1300 user accounts and operating systems files. It was his deletion of critical files that reportedly crashed the U.S. Army's network in Washington, D.C., for three days (McKinnon has claimed he did this by accident). The Department of Justice has argued that McKinnon's conduct significantly disrupted government functions and put national defense and security at risk.

McKinnon faces a potential sentence of up to 70 years behind bars in a U.S. prison. When his family heard the news, they were "stunned and frightened," Sharp recalls. As word spread online and in the UK media, people began to protest that the punishment was excessive. Sharp organized a campaign pleading for help for her son and got it in a most surprising way. A woman who had seen McKinnon on TV thought he exhibited signs of Asperger's syndrome and suggested that he get a psychiatric examination.

Like many people, Sharp was unfamiliar with the condition. "I thought it had something to do with being retarded," she says. But when she thought about her son's unusual behavior over the years—his fear of traveling, his obsessive behavior, his lack of social skills—it started to add up. McKinnon agreed to be evaluated by one of the world's foremost experts, Simon Baron-Cohen, director of the Autism Research Centre at the University of Cambridge.

Over the course of his research on autism, Baron-Cohen has become an authority on the emerging connection between Asperger's and engineering. "It makes sense that someone with Asperger's might be quite skilled at hacking," he tells *Spectrum*, "simply because one of the things they share is an understanding of systems, including computer systems." Baron-Cohen has found that more than 50 percent of people with Asperger's have an obsessive interest in technology, physics, and space. He has also discovered that autistic children are more likely to have engineer fathers and grandfathers than are normal children. He has even speculated that the rising incidence of autistic spectrum disorders may stem from a modern tendency for engineers to marry either other engineers or people who think like them.

After a 3-hour examination, Baron-Cohen found that McKinnon fit the profile. "He has got the classic patterns of Asperger's," he says. "[McKinnon has] a very narrow attention span and got totally obsessed searching for information about UFOs....The other feature that was pretty classic was this social naïveté, not thinking about how he might be perceived by others." Sharp says her shock at the news quickly faded to a sense of relief, as the diagnosis gave reason for behavior that had seemed so unreasonable for so long. "It began to make sense: how Gary was, how he can live in a dream world, how obsessed he was with what he did," she says.

Word spread of McKinnon's diagnosis, and he became an icon of Asperger's. In March 2009, Sting told the *Daily Mail* that it was "a travesty of human rights that Gary McKinnon finds himself in this dreadful situation. The British government is prepared to hand over this vulnerable man without reviewing the evidence." Members of Parliament lobbied on his behalf, including Andrew MacKinlay, who would later resign in protest after McKinnon lost appeal after appeal in the British courts. MacKinlay didn't think his fellow MPs were doing enough to protect McKinnon from being extradited when he was far from a terrorist.

McKinnon's diagnosis has not deterred the U.S. government from pursuing extradition. A spokesperson for the Department of Justice Criminal Division says the department can't comment on the unfolding case but stands by the indictment.

McKinnon wants to be tried for his crimes in a British court and has repeatedly asked the UK government to halt the extradition. In 2010 the UK home secretary finally agreed to review the case; she is also arranging for an independent medical expert to evaluate McKinnon. Baron-Cohen says the government may be making a life-or-death decision. After extensively interviewing McKinnon, he found him to be prone to depression and suicide. "If Gary McKinnon is sent to the U.S.," he said, "I fear he will kill himself."

KAREN TODNER, McKINNON'S ATTORNEY, says the home secretary should carefully consider McKinnon's mental faculties in making the decision. "Asperger's is not an excuse," Todner says, "but it certainly puts his actions in more of a clear light." As he awaits his legal fate, McKinnon remains under psychiatric care. He is barred from using his computer, and he refuses to speak with friends, family, or the press.

Some question the role of the syndrome in the crime. A blogger on AspieWeb, an online hub for people with Asperger's, challenges McKinnon for using the syndrome as "a scapegoat for your actions that are very illegal in order to get away with what you did. As someone who has Asperger's your actions are very offensive."

Courts are beginning to grapple with the Asperger's defense. In August 2009, Viacheslav Berkovich, a 34-year-old Russian immigrant in the United States diagnosed with Asperger's syndrome, received a reduced sentence after being convicted of hacking into a trucking company's computers in California. In 2008, a defense witness for Hans Reiser, a computer programmer convicted of brutally murdering his wife, testified that Reiser might have Asperger's. Defense attorneys also used the Asperger's defense for Lisa Brown, a 22-year-old convicted of murdering her mother. "Someone with Asperger's syndrome could still plan an act but, because of deficiencies in their social imagination, might be unable to see what the consequences of those actions might be," a psychiatrist said of Brown, who received a life sentence regardless.

COMMENTS?
Write to us at http://spectrum.ieee.org/autism/0711

Will Asperger's become a new kind of insanity defense? "The judicial system has not yet come to terms with Asperger's syndrome," says Brenda Myles Smith of the National Professional Development Center on Autism Spectrum Disorders. "We need to ensure that [the courts are] educated about this."

Part of the problem is that Asperger's is still relatively new to professionals and educators; it was added to the World Health Organization's diagnostic manual only in 1992. "The majority of people with Asperger's go undiagnosed," says Pat Schissel, president of the Asperger Syndrome and High Functioning Autism Association. "We need greater awareness of this in medical schools and the education system."

Maybe, just maybe, raising awareness of Asperger's could even curb more cybercrimes in the future. "It's an issue we should get on the table and start to address," says Jeff Sell, the Autism Society's general counsel and vice president of public policy. "These folks are very gifted when it comes to technology, and the potential is there for some type of concern." ❑

Parts of this article first appeared in IEEE Spectrum's Tech Talk *blog.*

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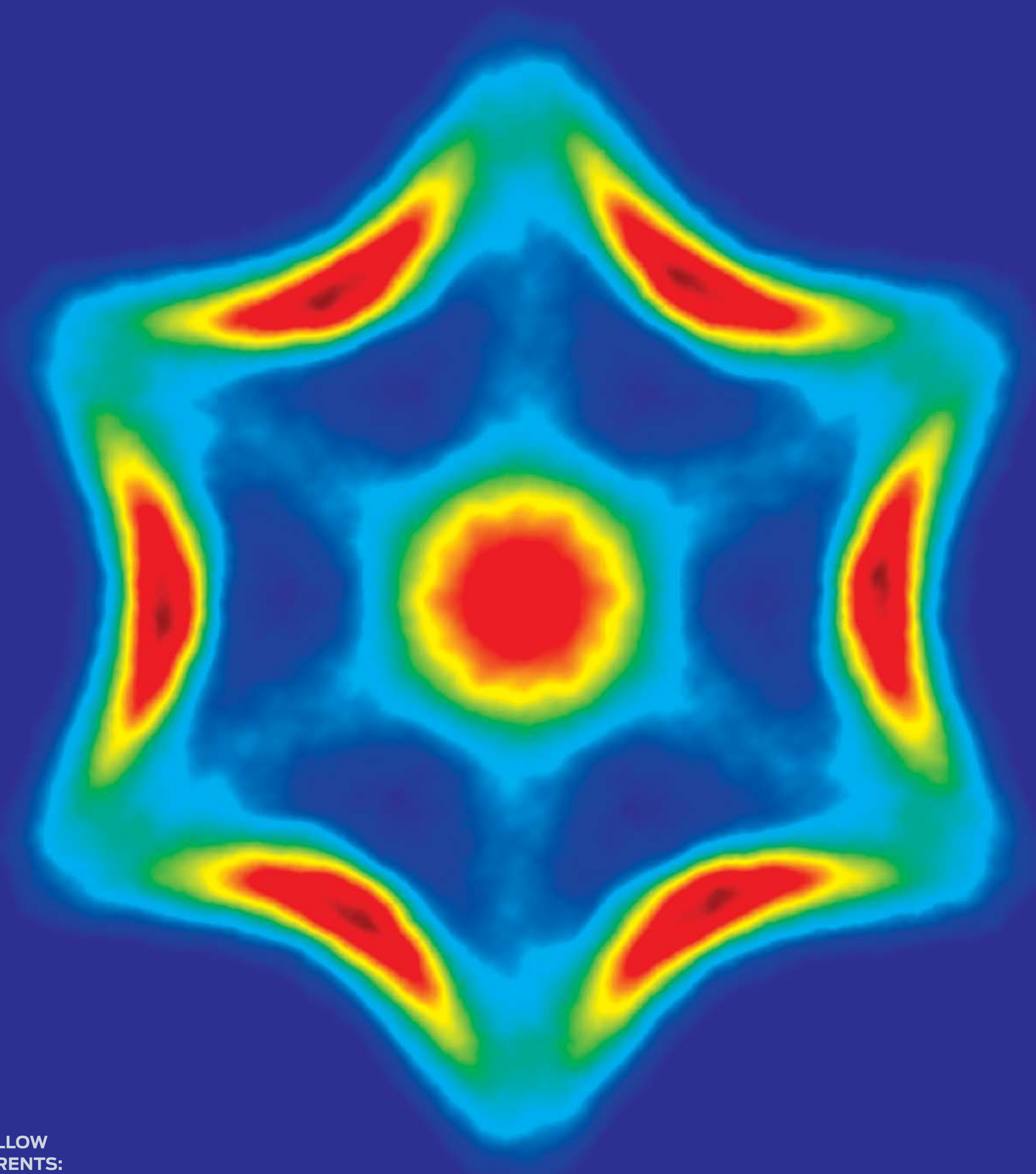

SHALLOW CURRENTS: This crystal of bismuth telluride, doped to serve as a source of negative charge carriers, conducts only on its surface.

IMAGE: AHARON KAPITULNIK AND ZHANYBEK ALPICHSHEV/ STANFORD UNIVERSITY

TOPOLOGICAL INSULATORS

QUANTUM MAGIC CAN MAKE STRANGE BUT USEFUL SEMICONDUCTORS THAT ARE INSULATORS ON THE INSIDE AND CONDUCTORS ON THE SURFACE

BY JOEL E. MOORE

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IN SCIENCE, THE USUAL ORDER is that experiments reveal something and then theorists explain it afterward, if at all. A classic example is superconductivity. It was first noticed in 1911, but it took theorists nearly 50 years to come up with an explanation, and even that explanation does not apply to every superconducting material. But once in a while, we theorists hit on things all by ourselves. And once in a *long* while, that something turns out to be technologically useful.

Now is one of those times. This is the story of a remarkable theory, hatched in the middle of the past decade, that experimentalists have been pursuing ever since. It is particularly sweet because it is linked to a branch of mathematics—topology—that had until now been mostly beyond any hope of practical application. And the discovery is about as straightforward as it gets: It is possible to produce materials that are insulators on the inside but conductors on the outside.

This is heady stuff, for engineers and physicists alike. The mobility, or speed, of the surface electrons in these materials is increasing dramatically every year. Just as important is their intrinsic stability, a quality that suggests they'd be robust enough to work in practical devices, such as extremely high-capacity interconnects and, one day, maybe even practical quantum computers. Physicists, meanwhile, are deeply intrigued by the possibility of using such materials to simulate new particles and other items of theoretical interest.

Topology is the branch of mathematics concerned with aspects of form that can't be fundamentally altered by stretching. A typical example is the hole of a doughnut: Let's say you deform the doughnut into the shape of a coffee cup. What had been the hole in the doughnut is now the "hole" in the cup's handle. Mathematicians call such features topologically invariant. They can, paradoxically, appear even in a seemingly formless substance such as an electron gas, produced when electrons are confined so that they move in only two dimensions.

In fact, the ability of such a gas to be topologically complex is what led to these new materials. Until recently, electron gases had been found only at the junction of two semiconductors having different electronic properties. These gases are crucial for high electron mobility transistors (HEMTs), a form of field-effect transistor used in radar, imaging, and other applications that require high gain at high frequencies. However, the idea of a 2-D electron gas that exists at the surface of an insulator—and is topologically protected from disorder—was a revelation that emerged from theoretical work done in 2005 and 2006.

Working independently, my group at the University of California (Berkeley and Santa Barbara) and researchers at the University of Pennsylvania and the University of Illinois predicted the existence of "topological insulators," which have insulating interiors but metallic surfaces. We also predicted that though these surfaces would be atomically thin, they would nevertheless be remarkably impervious to disorder and other effects that would tend to destroy their conductivity. That is, they would resist fundamental change, much as the hole does in a stretching, twisting doughnut.

Experimentalists confirmed these predictions in 2008, working with compounds of bismuth. This success triggered an explosion of experimental and theoretical work that continues to this day.

Because of their unique conductive properties, topological insulators will extend the bag of tricks available with electronic devices. There is reason to hope that these topological tricks will transform electronics by making it possible to create robust 2-D electronic gases of arbitrary shape and by allowing the simple manipulation of the spin of an electron. Electron spin is already a crucial property for magnetic storage in your hard drive; topological insulators may also allow it to be used for logic, replacing the microprocessor in your computer with a more energy-efficient and potentially faster design.

▸ ▸ ▸

First, though, a little background. Okay, a lot of background. (Remember, in this case the theory is not an afterthought; it's the main story.)

To understand topological insulators, you must first grasp how a conventional semiconductor junction creates a 2-D electron gas. This issue is not merely academic—the same technique (it's called modulation doping) used to create the best such gases for academic research is also used to create the HEMTs in cellphones and other demanding applications.

A central idea of quantum mechanics is that electrons confined to a small spatial volume take on the properties of electrons confined within atoms or molecules. Confined electrons can have only certain discrete energy levels, or "eigenstates." As an example, for the electron in a hydrogen atom the lowest such level—the energy that binds the electron to the nucleus—has an energy of 13.6 electron volts.

Scientists have learned how to confine an electron's motion in one, two, or all three directions, creating what are known as quantum wells, wires, and dots, respectively. Quantum dots are occasionally referred to as artificial atoms, because the confined electron's energy levels resemble those of an atom. In a quantum well, an electron moves freely in two directions, but in the third one it bumps up against a wall, called a trapping potential; if the trapping potential is strong enough, the electrons will be confined in the lowest-energy eigenstate in this direction. The electron can't change how it moves in this confined condition unless a shot of energy kicks it to an excited state, something that won't happen if the temperature's low enough. Consequently, we say that electron motion in the third direction is frozen out, that is, totally fixed; the electrons therefore move in only two directions. In other words, they're perfectly arranged in a plane, which we call a 2-D electron gas.

Semiconductors are good at creating these confined electronic states because they react sensitively to changes in their environment. Despite its name, a pure semiconductor is actually an insulator. To make it conduct first requires doping with an impurity that provides an excess of charge carriers, either electrons or holes. Properly arranged and packaged, devices consisting of several layers of these semiconductors will conduct well only when you apply an electrical field to one of the layers by means of an external voltage or current. In a 2-D electron gas, the charge carriers concentrate at the interface between two different layers—for example, a layer of gallium arsenide against one of aluminum gallium arsenide.

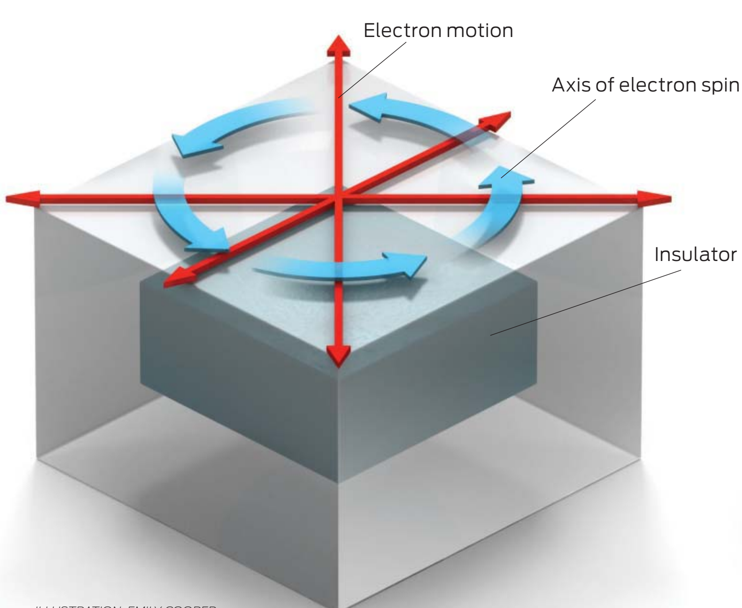
Modulation doping is a way of keeping the doping impurities away from the interface where the electrons travel. As a result, the charge carriers in the 2-D electron gas can move almost perfectly freely. At low temperature, in a gas contained in AlGaAs-GaAs structures, electrons can travel, on average, several millimeters before colliding with an impurity, a distance many times farther than in a typical metal.

The conducting nature of the surface layers of topological insulators has to do with an aspect of the electron's quantum soul: its spin. Spin is the elusive quantum-mechanical property that underlies magnetism. When the electrons in a region of a material all have the same spin state, that region becomes a magnet. This principle underlies all forms of magnetic storage, such as hard disk drives: When the spins of the electrons in an infinitesimal area of the disk are aligned one way, a 0 is stored there; if the alignment is in the opposite direction, a 1 is stored. Researchers are now attempting to create radically new "spintronic" devices that would exploit the spin of electrons rather than their movement.

So what exactly is spin? You'll be sorry you asked. Elementary physics tells us that any particle has an angular momentum determined by its motion through space. Consider a curve ball thrown by a baseball pitcher. The ball seems to have two types of angular momentum: Its center of mass is moving through space, but the ball is also spinning around some axis, and the spin's friction with air causes the ball to curve. For a baseball, the spin angular momentum is really just the ordinary angular momentum of the particles making up the baseball, and it decreases as the ball becomes smaller.

We can picture an electron as the limit of an infinitesimal baseball whose rotation speeds up as the ball becomes smaller. There is a catch: The electron has no "size," in accordance with our current understanding of quantum mechanics. And yet it still carries a small amount of angular momentum—its spin—even when sitting still.

SPINNING BULLET: Electrons on the surface of a topological insulator travel straight, along paths determined by their spin direction [blue arrows depict five such directions]. The spin of each electron is perpendicular to its path [red lines]; this phenomenon is known as spin-locking. The conductivity of the surface extends around the corners of the device.



READ, WRITE: These cones represent the effect of magnetic material on a topological insulator's electrons. Because they spin in lockstep when they move in a particular direction, the electron flow functions like a magnet, which means that a small current could be used to read the bits in an applied magnetic storage layer. A larger current could flip the bits, thereby overwriting the data.

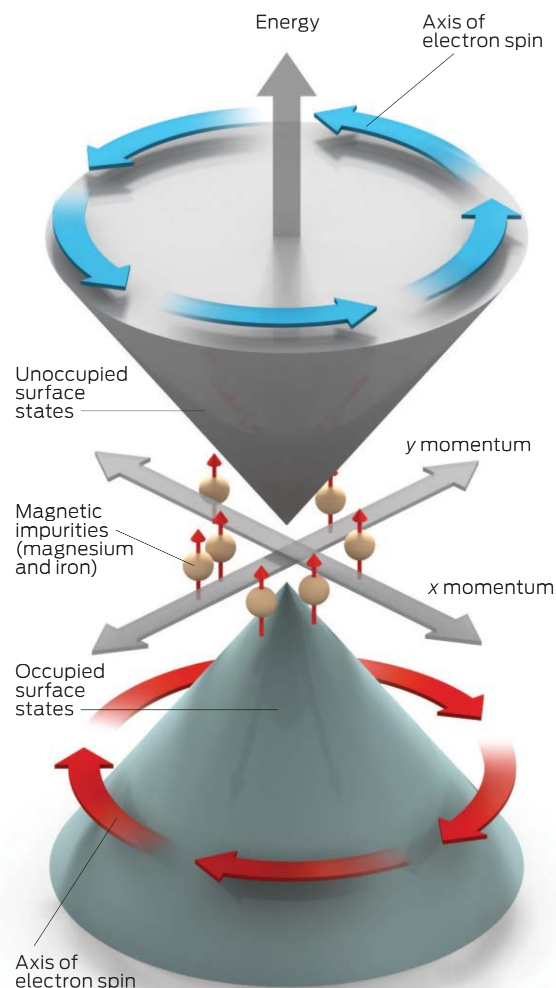
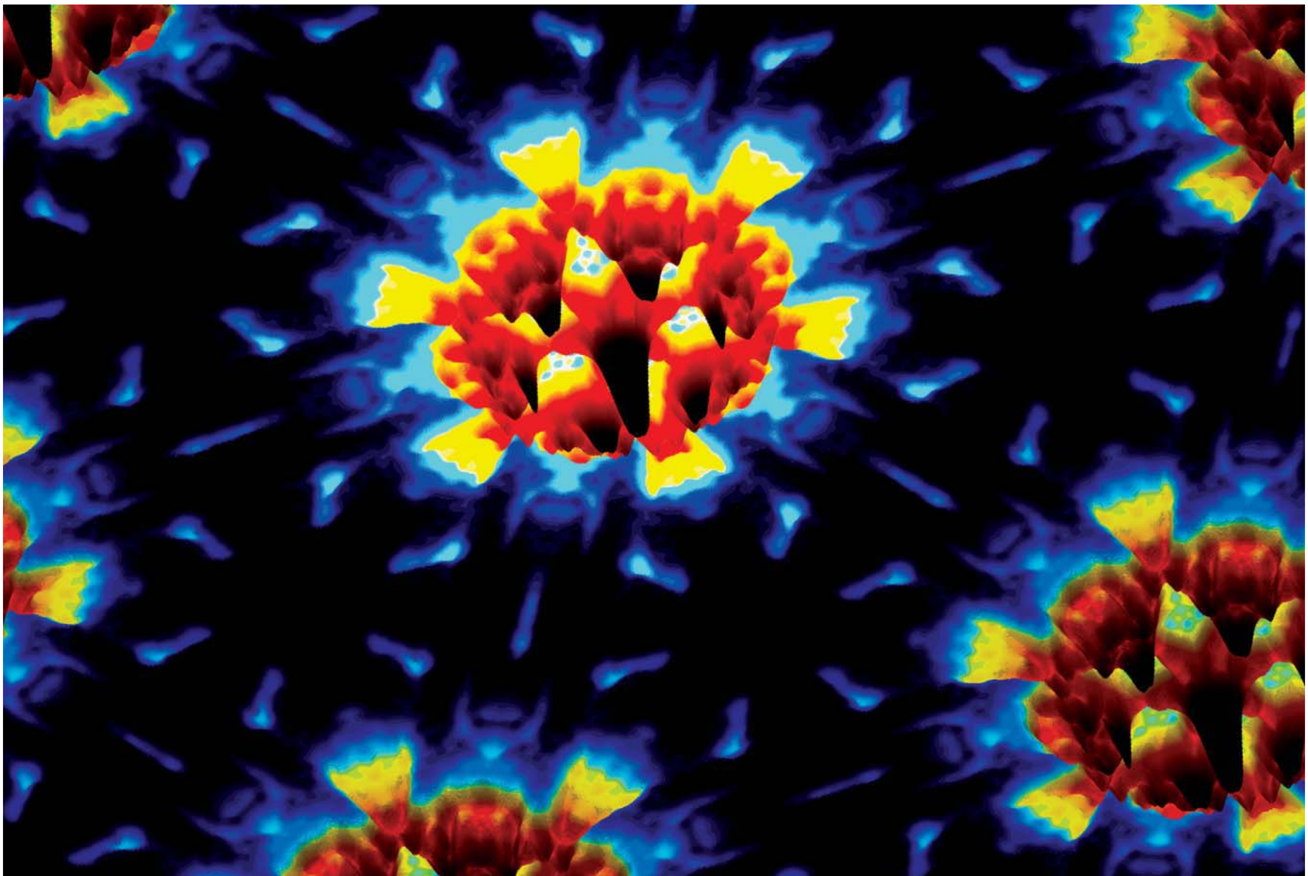
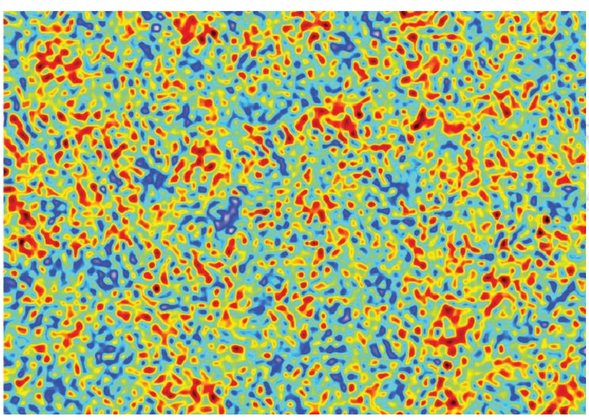
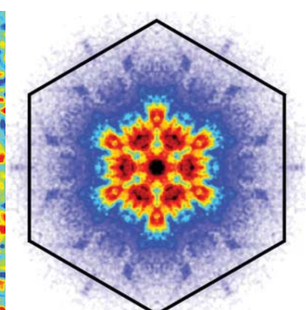


ILLUSTRATION: EMILY COOPER







UNSTILL WATERS: These patterns [top] form on a topological insulator when the wavelike nature of the electrons on its surface causes them to scatter off defects in the material and then combine with one another, sometimes reinforcing, sometimes canceling out. These images also provide evidence that the electrons are spin-locked, or moving in a direction determined by their spin. *IMAGE: ALI YAZDANI AND PEDRAM ROUSHAN/PRINCETON UNIVERSITY*

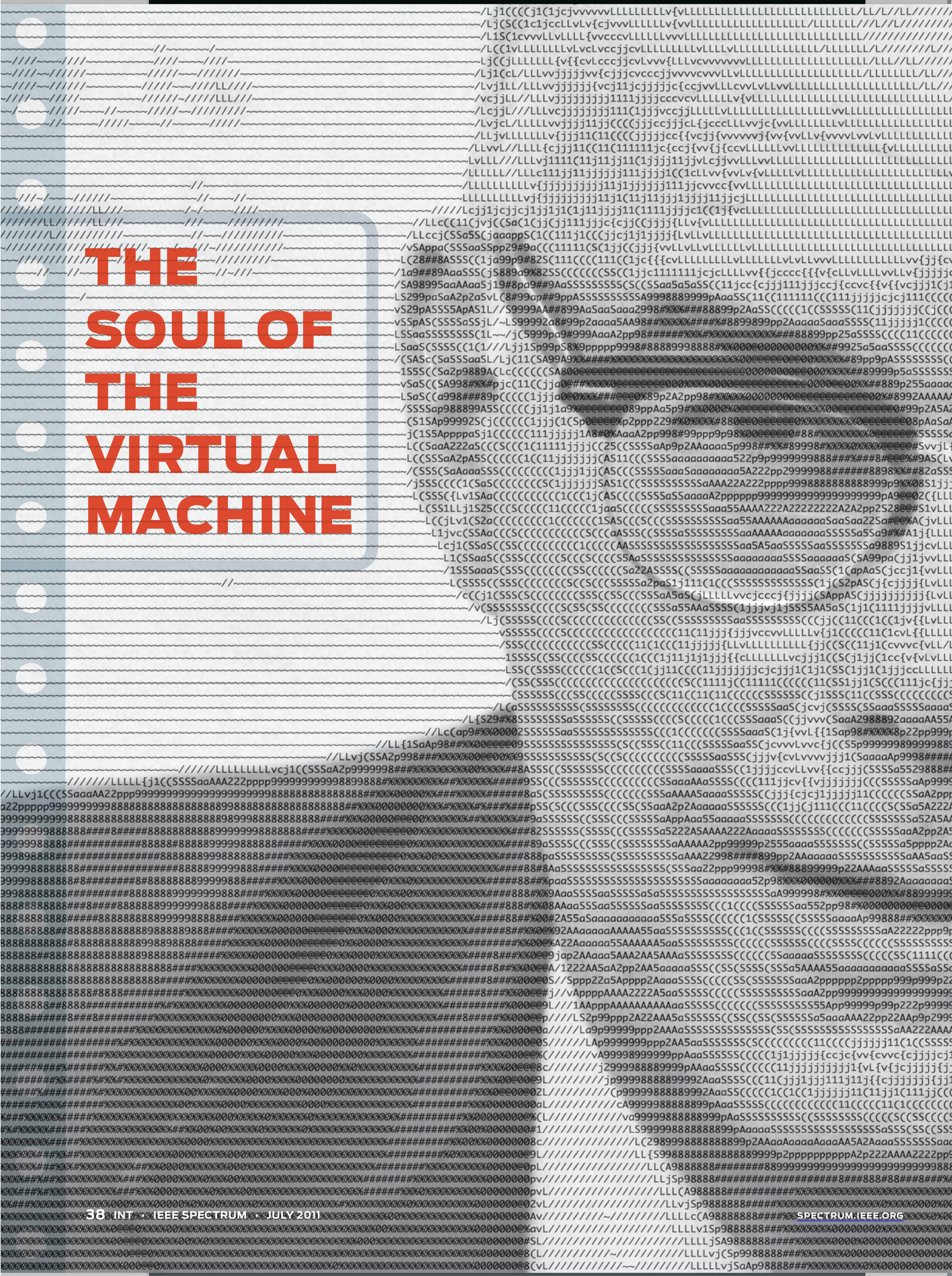
HOT SPOTS: This image [center] of the alloy bismuth antimony can be analyzed mathematically into a "map" [left] that shows visible disorder; despite this disorder, the surface remains conducting. *IMAGES: ALI YAZDANI*

One prediction of Einstein's theory of relativity is that when electrons are moving fast enough, their spin and their ordinary motion should interact. Spin interacts strongly with a magnetic field (thus its importance in magnetism), but a particle moving rapidly through an *electrical* potential sees an effective *magnetic* force on its spin. Although this interaction is very weak in such atoms as hydrogen, where the electrons move much more slowly than the speed of light, it becomes much stronger in an atom with a large atomic number, such as bismuth.

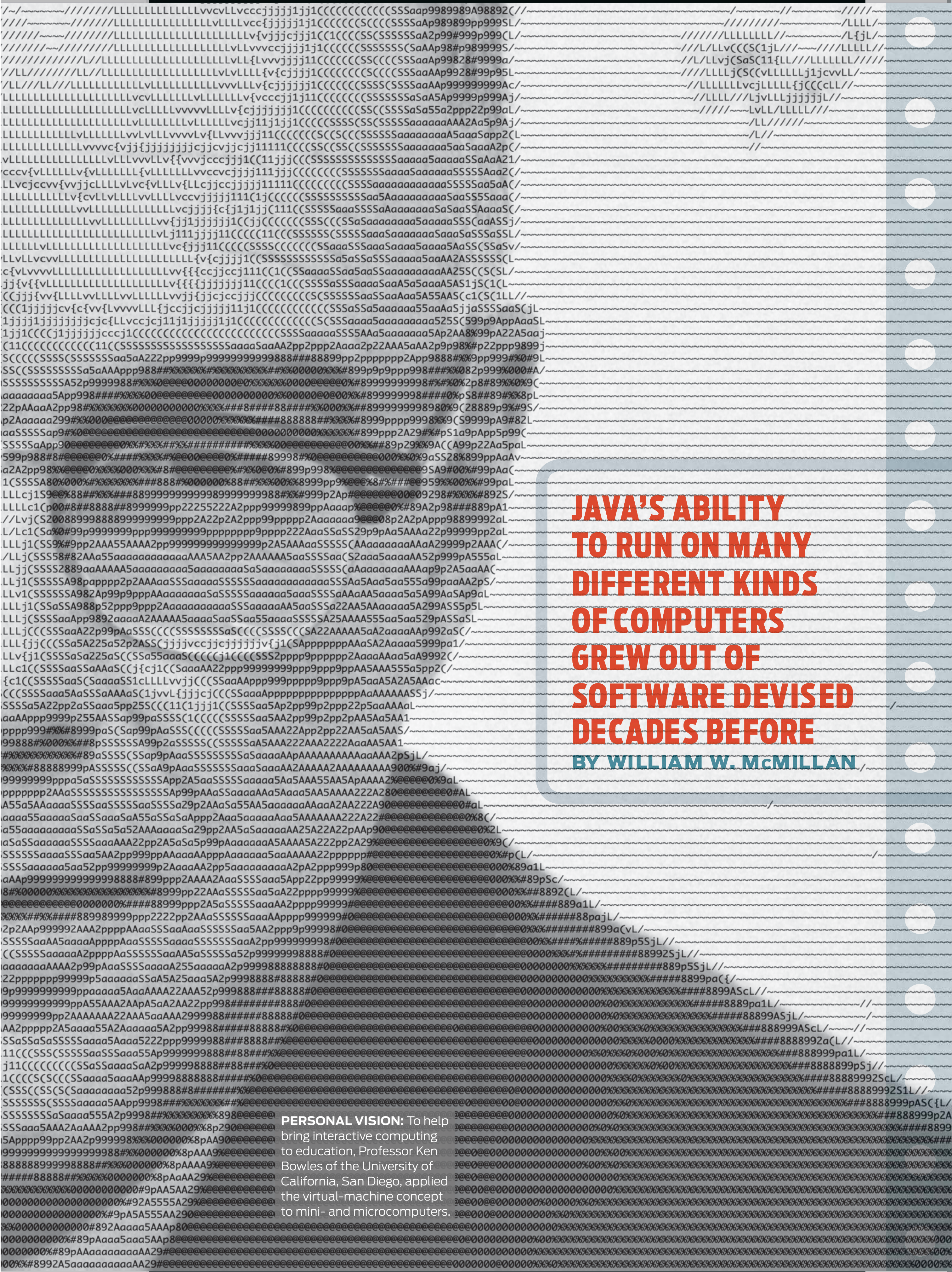
This "spin-orbit coupling" acts strongly on electrons moving through a semiconductor made of such heavy atoms. In a few materials, this force has a dramatic consequence: The material is no longer truly semiconducting. Instead, a chunk of the material is insulating in its center but conducting at the surface, where it has a 2-D electron gas. In rough terms, the electronic wave functions in the bulk are "knotted up"; unknotting them at the surface requires a metallic layer.

So why does this arrangement beat the obvious alternative, which would involve coating an ordinary semiconductor with a thin layer of metal? It turns out that the topological insulator surface differs in two key ways from that of other 2-D electron gases, and both are subtle results of the spin-orbit interaction.

First, there's the insulator's magnetic side. In a normal metal, an electron moving in a particular direction can have a spin axis that points in any direction. But in the metallic surface of a topological insulator, the spin axis is determined completely by the direction of the electron's motion. That is, all electrons align identically and rigidly with respect to the direction they're going in. So when they're all *Continued on page 52*



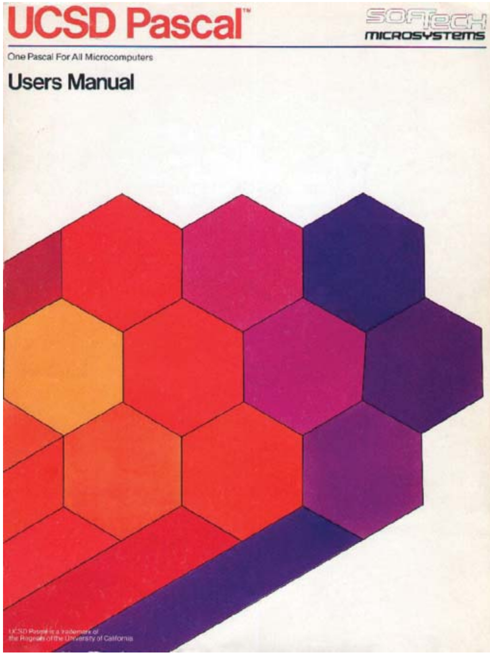
THE SOUL OF THE VIRTUAL MACHINE

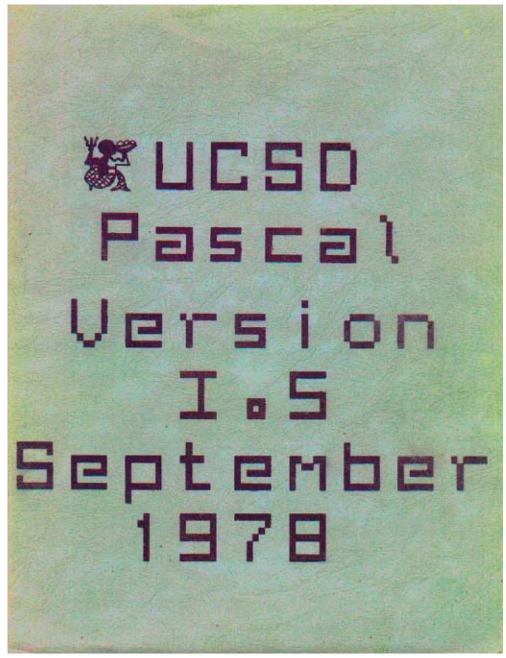


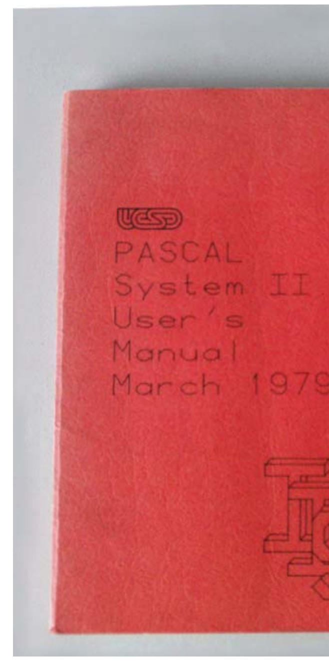
JAVA'S ABILITY TO RUN ON MANY DIFFERENT KINDS OF COMPUTERS GREW OUT OF SOFTWARE DEVISED DECADES BEFORE

BY WILLIAM W. McMILLAN

PERSONAL VISION: To help bring interactive computing to education, Professor Ken Bowles of the University of California, San Diego, applied the virtual-machine concept to mini- and microcomputers.







THE ENDURING APPEAL OF JAVA isn't hard to understand: With Java, you write code once and it can run on almost any modern computer or operating system—PC or Mac, Windows, Linux, OS X, whatever. It works that way because the Java compiler turns the source code into a kind of ersatz machine code that each of these different systems can execute when equipped with the proper run-time software. So different computers running different operating systems can all become, in programmers' parlance, Java virtual machines.

That wonderful write-once, run-anywhere capability has made Java the most popular programming language now in use and, by some measures, the most successful computer language of all time. But what you may not know, particularly if you don't have graying hair, is that this kind of software portability didn't start with Java (which Sun Microsystems released in 1995). Indeed, the roots of this approach date all the way back to the late 1970s and early 1980s, during the heyday of the Apple II, the first IBM PC, and many other personal microcomputers built by companies that are long gone.

Much of the relevant work took place at the University of California, San Diego (UCSD), and it influenced academic computer science, the design of the Pascal programming language, object-oriented programming, and graphical user interfaces. Although that work did not produce a commercial success, the story of these visionary programmers and their audacious plans offers some unique insights into how the computer industry evolved—for example, why the Apple Macintosh is what it is. It also explains how an accident of fate would later bring these ideas to the world again in the form of Java.

SEX, DRUGS, AND ROCK AND ROLL were ascendant on U.S. college campuses in the 1960s. But something else was, too: computer programming (although it was far less popular than the other three). At most universities, computers took the form of centralized batch systems—a Control Data Corporation 3600 at UCSD, for example. To use it, you had to translate your program into a stack of punched cards, which you would submit to the technical wizards who managed the computer. Then, after perhaps a day or two, you could return to the campus computing center to pick up reams of green-bar printouts, which you would pore over late into the night to try to figure out why your code hadn't executed properly. And after you found the bug in your code, you could go back to the card-punch machine to repair your logic or syntax.

Programming that way appealed only to the most dedicated. Starting in the late 1960s, however, a much better approach—interactive computing—beaconed from just over the technological horizon. And at UCSD, a young professor of applied engineering physics named Ken Bowles was determined to make it happen.

Before coming to UCSD, Bowles had witnessed the power of interactive computing at the Jicamarca Radio Observatory in Peru, where he had used a small Packard-Bell PB250 computer to control a massive antenna array and to collect data. So he knew firsthand how much small computers could aid research. He was also convinced that interactive computing could advance education in general.

Because of his deep interest in computers, Bowles was named to the com-

PREVIOUS PAGES: ORIGINAL PHOTO: ROBERT GLASHEEN PHOTOGRAPH COLLECTION/MANDEVILLE SPECIAL COLLECTIONS LIBRARY/UCSD

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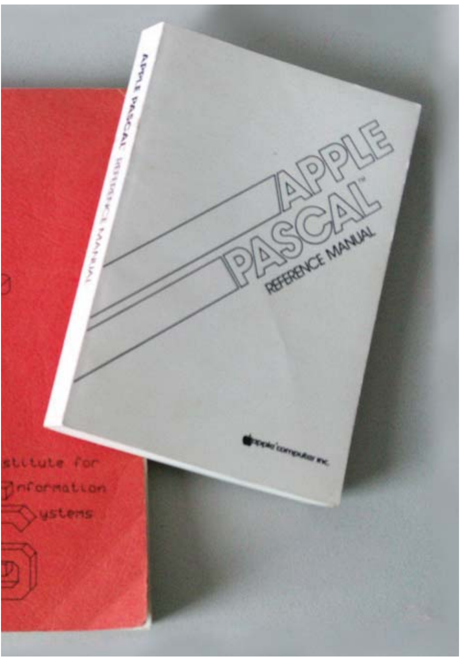


MANUAL LABORS: UCSD Pascal, developed in the mid-1970s [two photos, far left] and later offered to Apple II users in the form of Apple Pascal [center], was at the heart of the UCSD p-System, a multiplatform operating system that implemented a virtual "p-machine." Although the vast majority of the first IBM PCs ran MS-DOS, some used the UCSD p-System [right].

ABOVE, FROM LEFT: DAVID BARTO (2); BOB HOFKIN; BOB SANGUEDOLCE/COMPUTER HISTORY MUSEUM

mittee formed to find a new director for UCSD's computing center. That search failed, though, and in 1968 UCSD's chancellor convinced Bowles to take the job himself. UCSD's aging CDC 3600 mainframe needed to be replaced, giving Bowles the perfect opportunity to move his institution in the direction of interactive computing.

With that goal in mind, Bowles selected a Burroughs computer, in part because its designers were making strides toward interactive systems. Bowles and his students then began modifying the Burroughs operating system, making it more user friendly. All went well for a while, but during a 1974 lecturing trip to the University of Oxford, Bowles got word that UCSD had decided to replace the Burroughs machine, not with many smaller units but with big iron: an IBM mainframe. The university had also relieved Bowles of much of his authority as director.

The university took these actions to keep the computing center focused on administrative support, not better experiences for students. Rather than fight what would surely be a losing battle, Bowles stepped down as director, and his research into user-friendly operating systems was loaded onto a truck and carted away. One of his graduate students, Mark Overgaard, who had intended to work further on the Burroughs system, was left without a research topic.

Making the best of a bad situation, Bowles and Overgaard set out into uncharted research territory: They obtained a grant to use the LSI-11 minicomputer for education. The LSI-11 was a version of Digital Equipment Corp.'s then-popular PDP-11 with a central processing unit consisting of four large-scale-integration chips. Smaller than other PDP-11 models, it showed promise at the time as a platform for truly personal computing. Bowles and Overgaard aimed to apply the LSI-11 to a system for self-paced learning that Columbia University psychologist Fred S. Keller and his colleagues had popularized within educational circles in the 1960s—the "Personalized System of Instruction."

Bowles also worked with the late Alfred Bork, a computer scientist and educational technologist at the University of California, Irvine, to help create ways for students to use small computers to advance through topics as their mastery of the material allowed. Although he was a physicist and engineer, Bowles was working to forge tools for instruction in any academic discipline. He anticipated that students and teachers would write and freely exchange courseware and software, as is done in today's open-source community.

It was clear to Bowles that such software would have to include powerful commands for manipulating text, and it would also have to support complicated graphics—features few computer scientists of the era gave much thought to. Bowles also wanted the software to be portable. If you wrote a program for, say, an LSI-11, Bowles believed, you should be able to run it on a completely different kind of computer without having to modify the source code.

Bowles intended to create a computing environment that wouldn't require developers to relearn skills when they moved from one machine to another. Programmers wouldn't have to master a new set of monitor commands, a new debugger, or a new text editor—in the premouse era these used special key commands to manipulate the cursor. This environment, Bowles envisioned, should be able to run on a campus mainframe computer, on the minicomputers found in many research labs, or on personal computers, which he believed would increasingly appear in classrooms.

Bowles's new system was to be based on Pascal, a programming language designed by the Swiss computer scientist Niklaus Wirth in the late 1960s. Bowles recognized Pascal's superiority to the widely available BASIC, which was interactive and simple to learn but lacked adequate support for modularity and for programming using complex data structures.

But how could he ensure that this new system would be as portable as possible?

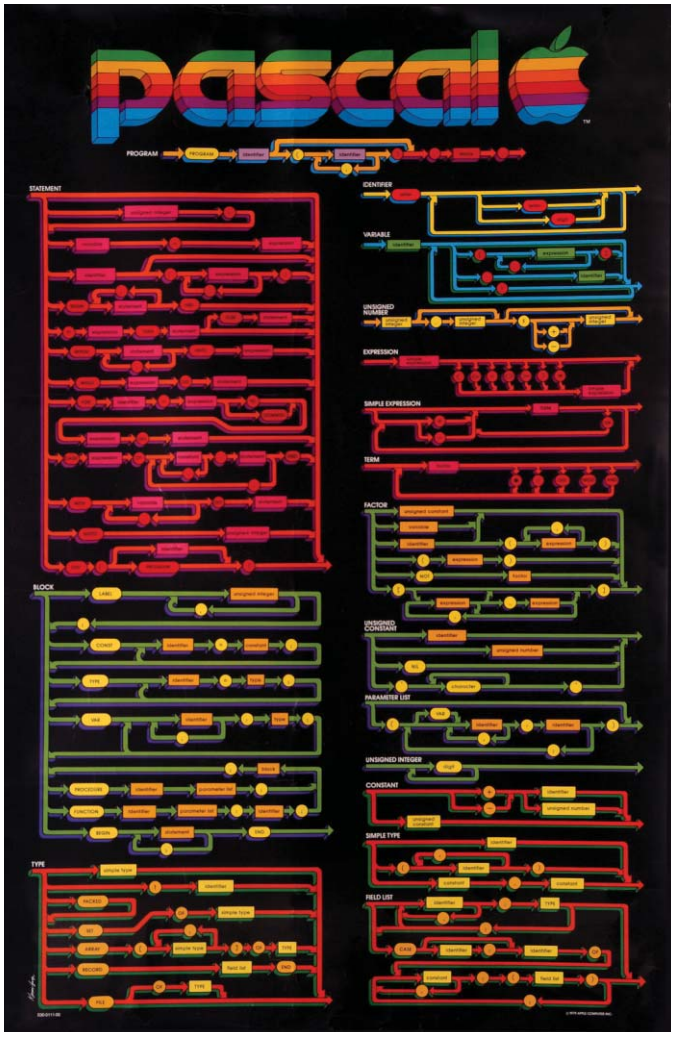
Urs Ammann, a student of Wirth's at the Swiss Federal Institute of Technology Zurich, had recently devised the perfect solution: Create a "p-machine" (the *p* stands for *pseudo*), which is to say a virtual machine, in software.

To appreciate what such a virtual machine is, you need to understand something about how computer programming is done. The central processing unit of a computer carries out very simple instructions—add one number to another, that sort of thing. These instructions are encoded and passed to the processor in the form of binary numbers, a sequence of 1s and 0s.

Writing a program directly in machine code is tedious in the extreme. People generally program in higher-level languages, whose instructions are considerably easier to understand: "If A equals B, execute command C," for instance. Special software translates such high-level instructions into the machine code that the processor actually runs. That special software is typically a compiler that is specific to the language you're using to write the program and the machine you want it to run on. A compiler that works on a Windows computer, for example, will not compile your program to run on an iPad.

The UCSD p-System included a compiler that translated high-level instructions into a machine code of sorts—but not one that would run on any computer of the day. The code was designed for a machine that didn't exist. A processor could in principle be built to run this flavor of machine code, but that wasn't the idea. Rather, the strategy was to write another piece of software that could translate this code on the fly into the current machine's native operations. With such software, your computer—no matter what kind of processor it had at its heart—could become, at least virtually, a p-machine.

Ammann wrote a Pascal compiler that generated what he called "p-code" for a p-machine, which was used to bring Pascal to several different mainframes.



RAINBOW COALITION: Ken Bowles teamed up with Apple Computer, which sold UCSD Pascal (rebranded as Apple Pascal) for its Apple II microcomputer, as evidenced by this colorful syntax chart for the language.

Bowles recognized the beauty of this approach, and his UCSD team adopted this strategy for use on micro- and minicomputers. UCSD's p-machine was slimmed down in some ways compared with Ammann's to meet the limitations of the many small computers of the time. By early 1976, Bowles's students had programmed the first UCSD p-machine in assembly language on a PDP-11.

To Wirth's relatively bare-bones definition of Pascal, the UCSD group added variables that could represent character strings (up to that point, the available kinds of variables could hold only numbers or at most one character each). The researchers included more powerful input and output operations, allowing you, for example, to access data in the middle of a file without having to read everything that came before it first. The group also added something called units, which were modules of code, each with a well-defined interface to other system components. Units were a step toward modern object-oriented design, in which the building blocks of a program are cohesive, reusable software modules that package data and code together.

In addition, the UCSD p-System included a file handler, a debugger, and a text editor for writing programs—all developed in Pascal and compiled into p-code. Graduate student Richard Kaufmann wrote the editor, one of the earliest to offer a full screen of text and a cursor that could be moved anywhere on the page using key commands. These software tools included drop-down menus, which appeared again much later in Apple's Lisa and Macintosh computers.

Although the initial UCSD p-System was developed for a PDP-11 minicomputer, some of Bowles's students also implemented a p-machine for microcomputers that used Zilog's Z80 microprocessor. The first test of the system's portability, carried out soon after that chip was introduced in July 1976, was an ambitious one: running the p-code for Kaufmann's text editor on a Z80. It operated flawlessly on the first attempt. The UCSD p-System was later ported to work with other chips, including the MOS 6502 (of Apple II fame), the Motorola 68000 (the original Macintosh chip), and the Intel 8086 family of microprocessors (used in the first IBM PCs).

Bowles and his students hoped the p-System would revolutionize how someone got an education. But for that to happen, they needed to get their software out to the world, which was no small trick in the pre-Web era.

Their first plan was to distribute the software themselves. Starting in 1978, UCSD students copied the p-System onto floppy disks and sent them to any-

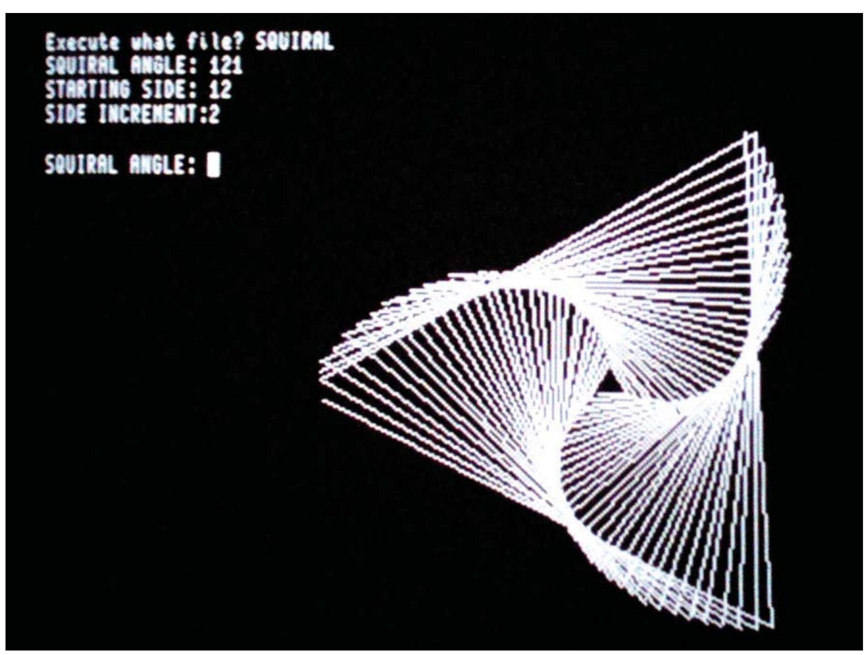
JEF RASKIN

MENU OPTIONS: A vintage green-phosphor video terminal shows the UCSD p-System running. Unlike other systems of the day, which required the user to memorize the various commands and then type the one required after the system's prompt, the p-System displayed a menu of options at the top of the screen.

one who paid the licensing fee. Bowles soon realized, though, that it would take more to bring the p-System to a truly wide audience. So he went searching for a commercial partner.

The earliest successful connection was with a company called Terak Corp., in Scottsdale, Ariz. The UCSD p-System was a natural fit for the computer Terak was marketing, which was based on the LSI-11 and had bit-mapped graphics, pretty jazzy for the times. Bowles worked closely with Terak's engineers, and Terak's desktop computers equipped with UCSD Pascal soon started appearing at universities around the United States. But bigger things were to come.

Bowles achieved his greatest commercial coup when he licensed the UCSD p-System to Apple for distribution on Apple II personal computers. He had begun nurturing a connection with Apple in 1977, when he met Steve Jobs at the introduction of the Apple II



JAZZY GRAPHICS: The UCSD p-System supported advanced graphics, which at the time made for impressive demonstrations, such as this one running on a Terak 8510/a.

TOP: BILL DEGNAN; BOTTOM: BOB HOFKIN

at the West Coast Computer Faire. Jobs wanted to foster relations with a university, and Bill Atkinson, an early and influential employee of Apple, showed interest in the p-System. The result was Apple Pascal, a packaging of the UCSD p-System for the Apple II. It ultimately sold tens of thousands of copies.

Bowles also tried to come to an agreement with Bill Gates. At the time, Microsoft Corp. had just begun positioning itself to enter the operating-system market. But Gates wasn't interested in paying royalties, and he ultimately purchased another operating system outright. It proved a wise decision. As we all know, IBM chose Microsoft's operating system, MS-DOS, for its line of personal computers, which began selling in 1981. But the University of California struck a deal with IBM, and buyers of early IBM PCs could obtain units equipped with the UCSD p-System if they chose.

> **"I HAD TO DO THIS ARCHITECTURE-NEUTRAL DISTRIBUTION FORMAT, AND THEN I JUST WENT *KA-CHING!* YOU KNOW, THIS P-CODE TRANSLATOR THING WOULD ACTUALLY JUST DROP IN THERE."**

For the university, the commercial success of the UCSD p-System, limited as it was, created legal difficulties under the federal tax code of the day. As a result, Bowles had to spin off the profit-making parts of the work on the UCSD p-System, which was done by licensing it to a Massachusetts company called SofTech Microsystems.

SofTech benefited from a very favorable licensing deal, but sales of the UCSD p-System nevertheless flagged as MS-DOS took off—even though Microsoft's product was technically inferior to the UCSD p-System in many respects. MS-DOS itself didn't include a full-screen editor for writing code (or for composing any sort of text document), nor did it come with a Pascal compiler or any other high-level language. More troubling, MS-DOS lacked easy-to-use menus. Its users had to struggle to remember the required syntax and then type the commands they needed, say, to delete a file or to create a new subdirectory.

Apple achieved something much closer to Bowles's vision of a friendly, easy-to-use computing environment when it introduced the Macintosh in 1984. No doubt the company's experience with Apple Pascal and the influence of the UCSD graduates that Apple employed helped make that possible. Nevertheless, MS-DOS dominated the personal-computer landscape for the rest of the decade, while Apple's operating system maintained a comparatively small foothold.

Luck and timing, of course, determined how much of this played out. But there was a technical reason, too, that the p-System failed to catch on during the early 1980s: Virtual-machine software is slower than native machine code. And in that era, before microprocessor clock speeds and transistor counts took off into the stratosphere, speed mattered a lot.

When Bowles realized that the UCSD p-System wouldn't make significant inroads into the operating-system market, he tried to convince SofTech to make the p-System available to run on top of other microcomputer operating systems, just as Java does today. But the firm's leadership didn't agree, a decision they must have ended up regretting.

So from the commercial demise of the UCSD p-System in 1985 until Java was released in 1995, there was essentially no way for a program compiled only once to run on more than one kind of computer. You could take, say, something written in C for one platform and compile it on a different one, but you'd have to make lots of fussy changes to the source code for the program to run properly. The task became even more vexing as graphical user interfaces became widespread, because such interfaces rely on routines built into the operating system. The user interface often constitutes most of the code in any given program, so amending it to run on a different kind of computer can be a major headache.

DON'T BE SHY
Write to us at http://spectrum.ieee.org/UCSD0711

In the early 1980s, while the UCSD p-System was still struggling to find a place in the hypersonically expanding microcomputer industry, James Gosling, a graduate student at Carnegie Mellon University, in Pittsburgh, was presented with a problem. His research group had acquired some rather unusual workstations, designed to run UCSD Pascal's p-code directly in hardware. Gosling's advisor figured that those machines didn't have much of a future, yet his group had a lot of software that ran on them. So he assigned Gosling the job of porting that code to a more established brand of minicomputers, Digital's VAX line.

Gosling could have done this by making the requisite fussy changes in every application program and recompiling. But he found an easier way: He wrote code that turned the VAX into a p-machine. Mission accomplished, he went on to obtain a Ph.D. based on completely unrelated work and soon took a job at Sun Microsystems. "Then fast-forward a bunch of years, when I was trying to do the project that Java came out of," said Gosling in an interview for *ACM Queue*. "I had to do this architecture-neutral distribution format, and then I just went *ka-ching!* You know, this p-code translator thing would actually just drop in there."

Java, the architecture-neutral programming language that Gosling and his colleagues at Sun developed in the early 1990s, achieved long-term success precisely because it focused on portability, which is what Bowles had tried to convince SofTech to do in the waning days of the UCSD p-System. Java virtual-machine software doesn't take over your computer; it doesn't include an editor or debugger; it simply runs Java programs—and it does it for almost any operating system. SofTech was in a position to create such a product a decade before Sun did, but it fumbled the opportunity. Java has since become the dominant software language in the world.

And what became of Ken Bowles? He took early retirement from UCSD in 1984 to work on the standardization and promotion of the Ada programming language, which is largely derived from Pascal. Since 1995, he has immersed himself in the world of wildflowers, photographing them and working with botanists on their classification. He built a website that displays his work and wrote code to support it. His language of choice is Delphi Pascal, which owes a great deal to the ideas first embodied more than three decades ago in UCSD Pascal.

It just goes to show that old programming languages that are any good never actually die. They just fade into ones that go by other names. ❑

TURNING SWEAT INTO WATTS

Exercise machines that generate electricity are the latest fad. But do they make sense? BY TOM GIBSON

WALK INTO A SPINNING CLASS AT THE NEW YORK SPORTS CLUBS' facility on Eighth Avenue and West 23rd Street in Manhattan and you'll find 20 sweaty people furiously pedaling their stationary bikes. Look closely and you'll notice something unusual about this workout: Each of the bikes is attached to a black box with wires running out of it. The box is a compact generator that converts the motion of the wheels into electricity, which is then fed into the power grid, offsetting some of the club's energy use. For these gym-goers, it's not just about their cardio fitness; their sweat is helping to make the planet a bit greener.

MCKIBILLO

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BY ADOPTING POWER-PRODUCING exercise machines in this way, gyms can promote themselves as environmentally friendly and also reduce their electric bills. At least three start-ups in the United States are now selling equipment to retrofit aerobic machines—stationary bicycles, elliptical trainers, and steppers—into electricity-generating gear. These companies have already converted several hundred machines at dozens of U.S. health clubs and university gyms.

The reality, though, is that this technology faces major hurdles before it can go mainstream. For one thing, the economics aren't very enticing. The energy output from a single exercise machine is quite small: Unless you're Lance Armstrong, you might be able to power a ceiling fan while spinning a stationary bike, but not much more. So a gym might have to wait decades to recover the money it spent converting its exercise machines to generate electricity. What's more, the energy output of these machines is so low that the environmental benefits they provide are scant. So don't expect that fitness enthusiasts pedaling stationary bikes are going to free the United States from its addiction to fossil fuels.

Backers of the technology respond by comparing the current cost of these machines with that of technologies like compact fluorescent bulbs or solar and wind power, which many people doubted would ever take off. They claim it's only a matter of time until every exercise machine comes equipped with a generator. And with some 30 000 gyms in the United States, that would mean millions of machines—and many more in people's homes—whose combined energy would then be appreciable.

"Stationary bikes create resistance, and through this friction, heat is produced," says Jay Whelan, cofounder of the Green Revolution, in Ridgefield, Conn., the company that converted the spinning bikes at the NYSC in Manhattan. "The industrial engineer in me said, 'What a waste! There's got to be a way to capture and use this energy.' "

DON'T STOP: Retrofitted by a company called the Green Revolution, exercise bikes at a New York Sports Clubs gym generate electricity; a display shows the biker's wattage.

PHOTOS: STAN HONDA/AFP/GETTY IMAGES

ALTHOUGH THE BASIC IDEA of attaching a generator to exercise equipment is many decades old, the press started lavishing attention on this concept four years ago, after a Hong Kong gym called California Fitness rigged 18 exercise machines to charge a battery and power fluorescent lights. Since then, three companies in the United States have been working hard to market the technology, each taking a slightly different approach.

In 2007, Hudson Harr, then a 21-year-old graduate of the University of Florida with degrees in electrical and mechanical engineering, spent all the money he had amassing a collection of used elliptical machines and electrical parts. Transforming his mother's house into his laboratory, he began tearing the equipment apart. What he found is that some elliptical models already had small DC generators inside. These power the monitoring console and also serve to increase the amount of resistance the user feels when exercising. That's because the current generated creates a magnetic force that opposes the motion that creates this current. By adjusting the amount of current created, the user can vary the resistance he or she feels.

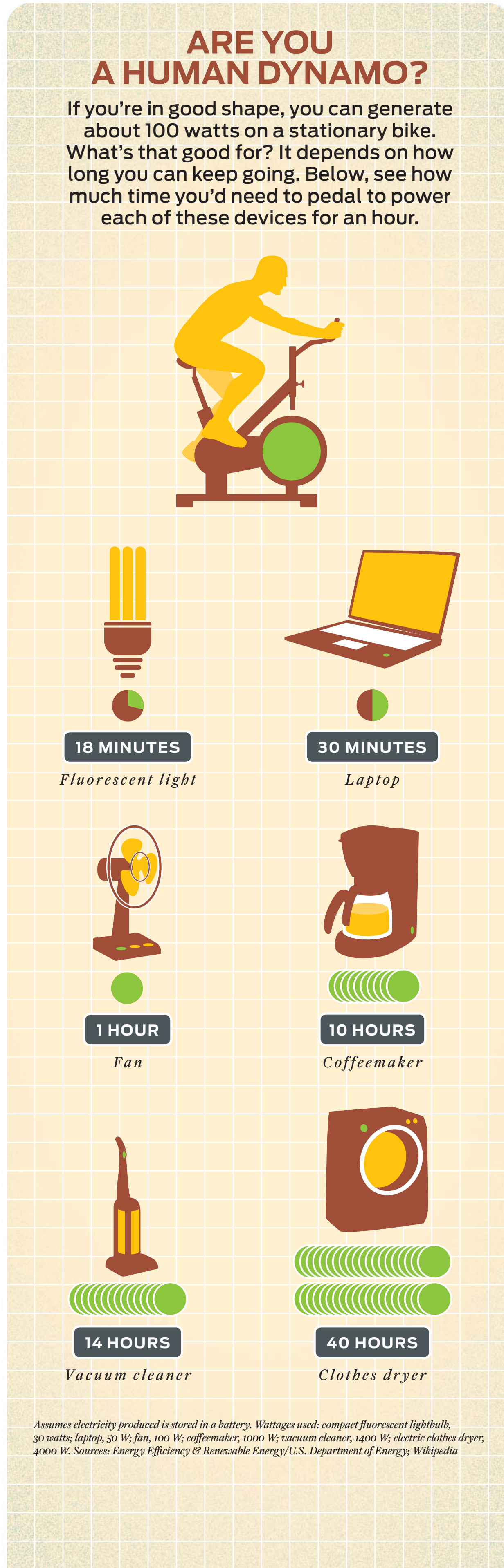
Normally, the generator uses a bank of resistors to dissipate the energy it produces. Harr figured that he could get rid of the resistors and put that power to work. "Essentially, we remove the internal resistance the machine has and give it an external load, which is our equipment," he says. Harr's strategy is to wire each elliptical machine to a central unit containing an inverter that converts the DC power generated to AC. The inverter in turn connects to the building's electrical system and ultimately feeds the grid.

Harr's lab is no longer taking up space at his mother's house. His company, ReRev, based in Clearwater, Fla., has moved into a 1400-square-meter production facility and now employs 15 people. ReRev has wired up 150 machines at more than a dozen gyms. It has installed systems at many colleges, including Drexel University, James Madison University, Oregon State University, Texas State University, and the University of Florida.

Meanwhile, the Green Revolution, the company Jay Whelan and Mark Sternberg founded in 2008, went down a different road. Instead of elliptical trainers, the two entrepreneurs focused on exercise bicycles. They started by taking an ordinary bike and propping its back wheel up on a triangular frame. Then they attached a car alternator to the wheel and hacked it to boost the amount of power it could generate, which also raised the resistance to motion it provided.

Their initial idea was to design and build entirely new exercise bikes with generators attached to them. But the owners of exercise clubs didn't want to buy all new equipment, so the two entrepreneurs decided to build a power-producing modification instead. Their module attaches directly to the bikes, feeding electricity to two 12-volt batteries wired in series. When a user starts pedaling, the batteries charge, and when they're full, the inverter kicks in and sends power to the grid, converting 24-V DC to 110-V AC.

Although the Green Revolution decided not to build custom equipment, that's exactly the approach another entrepreneur in this field has taken. Mike Taggett attended the University of Arizona, where he majored in Latin American studies. He worked as a river guide and started a business making an eyeglass retainer that he'd invented himself. At a trade show sometime in the late 1980s, he had the idea of attracting visitors to his company's booth by bringing a converted exercise machine that would generate electricity and power lights and kitchen appliances. "We made smoothies," he recalls.



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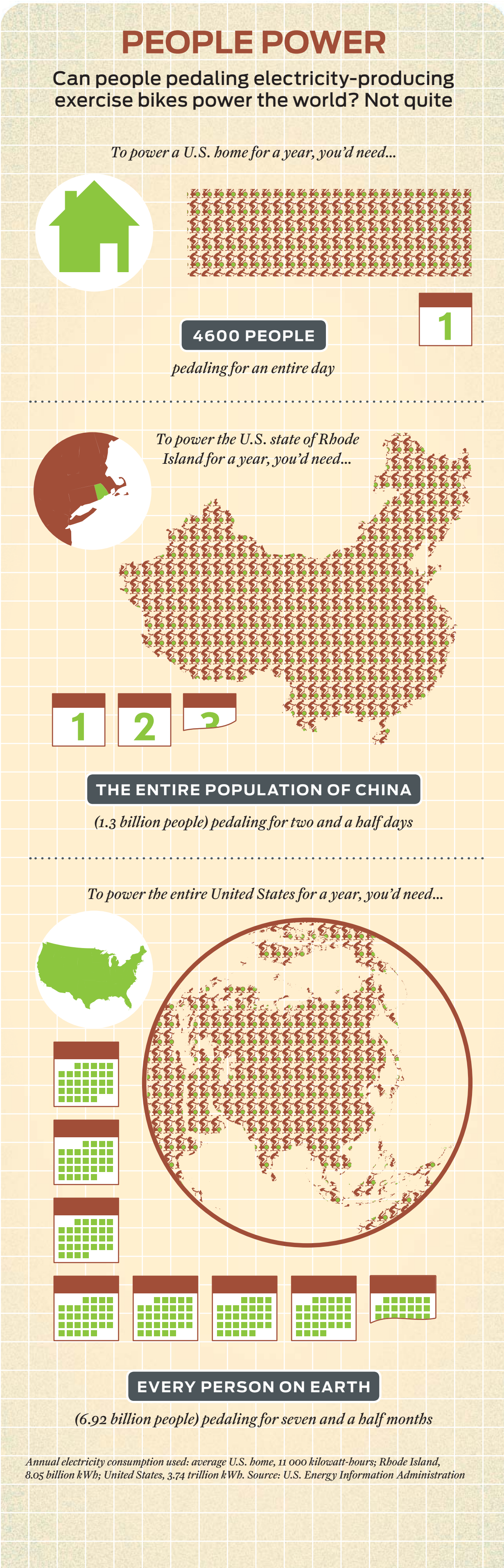

That demonstration was the seed of an idea that grew in Taggett's mind over the next two decades. A few years ago he got to work, and in 2008 he unveiled the Human Dynamo, a custom-designed power-producing stationary bike—with a twist. In addition to the usual pedals, the machine has hand cranks to provide a rigorous upper-body workout and generate even more electricity. With their sprockets chained together, the hand and leg cranks spin at the same speed to turn the bike's 45-centimeter-diameter flywheel about 300 revolutions per minute during a typical workout. A belt connects the flywheel to the generator, which spins at something like 1500 rpm.

You can connect several of Taggett's machines together to drive a single generator. He calls this configuration the Team Dynamo. "You really cut down expense and maintenance because you have one big generator and one electronics package for up to 10 machines," he says.

IT MIGHT FEEL LIKE A LOT if you're generating it, but just how much energy are we talking about here? An elite cyclist can produce more than 400 watts, more than half a horsepower, for an hour or more at a stretch. But a regular person, even somebody in good shape, can average only 50 to 150 watts during an hour of strenuous exercise. If you could capture that power to produce electricity, what would it be good for? Not much, really. It could power a television set for about an hour, which might keep you entertained while you pedaled away to produce the electricity in the first place.

Still, might this be a reasonable way for a gym to offset at least some of its electricity use? Let's assume that the average piece of exercise equipment is in use 5 hours a day, 365 days a year. If each patron generates 100 watts while using it, that machine creates some 183 kilowatt-hours of electricity a year. Commercial power costs about 10 cents per kilowatt-hour on average in the United States, so the electricity produced in a year from one machine is worth about US $18 dollars.

The companies selling the retrofitted equipment say that costs vary on a case-by-case basis, depending on the kind of equipment the gym has and its electrical installation. But according to some reports, it costs a gym at least several hundred dollars—perhaps as much as $1000—to purchase the equipment or equipment modifications needed to harvest this electricity from a single exercise machine. Earning just $18 a year from it means that the initial investment would take decades to pay back. Other energy-conserving investments a gym might consider, such as installing better insulation or adding solar water heaters for the showers, typically have payback periods of several years.

So are these electricity-producing exercise machines merely a marketing gimmick, something to make gym patrons feel good about their workouts? At the moment, that would seem to be the case. Gyms that have embraced the technology say that by advertising themselves as greener than regular gyms—and gyms are notorious power hogs—they can attract environmentally conscious customers. And if enough

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customers choose that gym rather than another one down the street, the initial investment will pay for itself much faster.

Take the Green Microgym in Portland, Ore. Adam Boesel opened the facility in 2008 with Human Dynamo machines inside and solar panels on the roof. Boesel reports that his gym generates about 36 percent of its own electricity, saving nearly 40 000 kWh per year—although he admits that the savings come mostly from the solar panels.

"People are very receptive," says Boesel. He even initiated a program called Burn and Earn, which rewards customers with $1 coupons—redeemable for food, beverages, clothing, and other merchandise—for every hour they operate the electricity-generating equipment. The electricity produced certainly isn't worth a dollar to him. And he'll be lucky if he's still in business when the electricity generated from the machines finally compensates for the extra money he spent on them.

But this might change in the not-too-distant future, if the companies selling retrofitted equipment can ramp up volume and bring costs down. Or if the mainstream manufacturers of exercise machines catch the wave and add an electricity-generation option to their products without charging a large premium for it. If including that feature ups the price only $100 or so—a reasonable prospect given the very minor alterations needed—the payback period would rival that of many other conservation measures.

Boesel can't wait. "I hope this technology is in every piece of equipment in 10 or 15 years," he says. "A few watts here and there from all of us as we sweat may add up to something significant." ❑

JOIN THE DISCUSSION *Post your comments at* http://spectrum.ieee.org/greenbikes0711

ENERGIZED: Powered by four people, the Team Dynamo machine uses a single generator [top]; elliptical equipment at California State University, Chico [bottom], uses generators by ReRev.

PHOTOS: TOP, HENRY WORKS; BOTTOM, REREV

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TOPOLOGICAL INSULATORS

Continued from page 36

going in the same direction—as part of a current—they collectively function as a magnet. This effect is present in ordinary quantum wells but is 100 to 1000 times as strong in topological insulators.

Researchers have proposed several devices that take advantage of this strong coupling between current density and magnetic moment. Imagine putting a magnetic layer, such as that used to store bits in a hard disk, on top of a topological insulator. By running a small current in the topological insulator, one could efficiently read bits stored in the magnetic layer; by running a larger current, the spin density induced in the topological insulator could flip the state of the magnetic bit, thereby writing over it.

Second, topological insulators are wonderfully robust in the face of disorder. They retain their unique insulating/surface-conducting character even when dosed with impurities and harried by noise. This ability is just another manifestation of a paradox of quantum behavior, which is unpredictable on a quantum level but highly reliable on a macro level.

Such robustness was apparent in superconductivity, the first macroscopic quantum behavior discovered, as well as in its related phenomenon, superfluidity (the ability of supercold helium to flow without viscosity). Both superfluids and superconductors show their properties in real materials that invariably contain impurities and inhomogeneities.

One source of this robustness is the topological invariance mentioned earlier. Just as the hole in a doughnut remains a hole even when you wrench the material into the shape of a coffee cup, 2-D electron gases have robust topological states that retain their character in the face of disorder. These states were originally observed in such gases only at very low temperatures and in very high magnetic fields.

In the summer of 2006, the three research groups mentioned above predicted the existence of topological insulators by considering the possibility that topological invariants may come from spin-orbit coupling. As one of the people involved in these predictions at the University of California, I can give some anecdotal insight into how they came to happen.

We were inspired by a key 2005 paper by Charles Kane and Eugene Mele of the University of Pennsylvania. It explained a model system in one lower dimension: A 2-D system such as a quantum well can have one-dimensional quantum wires at its edge, generated by spin-orbit coupling.

COMMENTS? *Write to us at* spectrum.ieee.org/insulator0711

At that time, physicists had already found many topological states in 2-D systems, both experimentally and theoretically, but the Kane-Mele proposal was different in several obvious and not-so-obvious ways. I spent the spring of 2006 working with Leon Balents of UCSB to find a different formulation of the work of Kane and Mele that would let us understand its connection to these older phases. After a few weeks of intense mathematical fiddling, usually with a World Cup match playing in the background, it became clear that there could be a 3-D version of their state, which was quite a surprise since we (and others) thought of topological states as requiring 2-D systems and low temperatures.

Interest in topological insulators remained somewhat limited until the experimental discovery of the first such material (a bismuth-antimony alloy) by a Princeton/Lawrence Berkeley National Laboratory team led by M. Zahid Hasan. Their measurement, published in *Nature* in 2008, found clear evidence for the distinctive surface electronic motion predicted by theory. That began a rush of discoveries that have continued unabated, including the discovery of the second-generation topological insulators bismuth selenide and bismuth telluride. These materials are expected to show topological insulator behavior up to room temperature in sufficiently small samples and have surface metallic layers only a few nanometers thick.

Of course, this being quantum physics, it gets even weirder. It turns out that an electron moving in a semiconductor has an effective mass that can be very different from its mass in a vacuum—a factor of 10 in either direction is not unusual. It's like a horse that can turn into either an elephant or a dog. And it means that the electrons at the surface of a topological insulator, unlike those in an ordinary 2-D electron gas, have an effective mass of *zero*.

Strangely enough, zero-mass electrons had already been known in another exotic environment, that of the 1-atom-thick sheet of hexagonally arranged carbon atoms known as graphene. The origin of the zero-mass effect in graphene has nothing to do with spin, but it has a similar technological implication: It can enable very fast electronic devices. For instance, the first 100-gigahertz transistor was recently demonstrated by IBM scientists using a device based on graphene.

The zero-mass effect of topological insulators allows other possibilities less obvious than fast devices. For example, the number of charge carriers in a zero-mass material is much more sensitive to an applied electrical field than in a typical semiconductor. This process is known as field doping, in an analogy to the standard process of controlling carrier density by chemical doping, but it has an advantage that chemical doping does not. You can reverse field doping rapidly by changing the electrical field, whereas chemical doping is essentially permanent.

Put together all these advantages—fast electrons, sensitivity to applied fields, reversibility of doping, and robustness in the face of noise—and you can see why topological insulators have excited the engineering community. They may even help us build one of the chief objects of desire of applied physics: the quantum computer. Scientists at Microsoft and elsewhere have stated their belief that the topological quantum computer is the most viable route to this goal, and one design for such a computer is based on interfaces between topological insulators and superconductors. But there remain some daunting practical challenges in making such interfaces operate reliably at useful temperatures.

It is possible that topological insulators and graphene will be remembered as the first materials to be experimentally discovered in the 21st century that compare with the great accomplishments of the 20th. The range of possible technologies enabled by these remarkable materials is becoming clearer, and far more is likely to come than we can now discern. ❑

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

Thiruvananthapuram, Kerala, India – 695 547

Faculty Positions in Department of Avionics

Indian Institute of Space Science and Technology (IIST), India's first Space Institute established by the Department of Space, Government of India, offers undergraduate (Avionics, Aerospace Engineering and Physical Sciences), post graduate and doctoral programmes in niche areas of space science, technology and applications. IIST is located at Valiamala, 18 kms from Thiruvananthapuram city, on the way to the famous hill resort of Ponmudi. IIST fosters state-of-the-art research and development in space studies and creates a think-tank centre to explore new directions in Indian Space Programmes.

The campus nourishes a co-operative learning environment enriched by the challenges of the Indian Space Programmes. At IIST, research is an integral component which goes beyond the run-of the-mill Cartesian-based teaching. We provide the best research ambience which nurtures complete freedom for academic expression and advanced research, with adequate financial support for innovative ventures.

Department of Avionics
The Department of Avionics, with a well-knit symbiosis of Electrical, Electronics, Communication Engineering and Computer Science, has the vision of producing Engineers/Scientists/Technologists of the highest calibre in Space Electronics. Equipped with the most advanced teaching and research laboratories, the department has extensive research scope in the following areas:

- Control Systems
- Embedded Systems
- Semiconductors
- Signal Processing
- Image processing
- RF and Microwave IC Design
- Antenna Design
- Digital Communication
- Wireless Communication
- Fibre Optics Communication, Fibre Optic sensors
- VLSI and ASIC Design
- Wireless Sensor Networking
- Measurement and Instrumentation
- Power electronics and drives
- Robotics
- Virtual Reality

The Department seeks exceptional candidates, for faculty positions in the rank of Assistant Professor, with a passion for research and teaching in the above areas. Outstanding candidates may also be considered for the post of Professor and Associate Professor, on exceptional grounds. Candidates committed to high standards and professionalism in the alcoves of specialized knowledge, who can develop and sustain a strong research programme, as well as take up new challenges in space studies, may apply. A Ph.D. degree in the area of specialization from a reputed university is required.

If you are interested in contributing to the national space programme, where space studies, technology and application converge to solve real problems, please visit **www.iist.ac.in** for more information.

The Faculty of Electrical and Information Engineering of the Graz University of Technology, Austria, is seeking to fill the tenure-track position of a

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as soon as possible.

We are looking for a well-qualified and scientifically distinguished person capable of representing the field of Computer Engineering in research and in teaching. We expect an ambitious, forward-looking and application-oriented research program in the area of Computer Engineering with a focus on hardware and software for distributed embedded systems. Emphasis should be on one or more of the following areas

- Real-Time Embedded Systems
- Hardware/Software Co-Design
- Power-Aware Computing
- Distributed Systems

Graz University of Technology has an equal-opportunity policy and aims to increase the number of women in its ranks, especially in leading positions and among the scientific personnel. Qualified women are particularly encouraged to apply. In case of equal qualification, preference will be given to women.

Candidates are asked to submit their applications including the customary documentation, such as copies of certificates, curriculum vita, list of publications, summary of previous and planned research and teaching, a concept for the future direction of the department of Computer Engineering, copies of the five most important publications, names of references and a statement of willingness to move to Graz. These documents should be submitted both in hardcopy and in electronic form to the Dean of the Faculty of Electrical Engineering and Information Technology, Graz University of Technology, Prof. H. Stigler, Inffeldgasse 18/EG, A-8010 Graz, Austria, e-mail: zavec@tugraz.at.

The application including all documentation must arrive at the Dean's Office latest by **01. August 2011 (Date of mail stamp / e-mail)**
Further information and details can be found on http://www.e-i.tugraz.at/dekanat

The Dean: Stigler

Government of Bermuda
Ministry of Public Works

Principal Electrical Engineer

PS 36-38 $113,480-$122,064
(US$ equivalent)
Department of Works and Engineering
Ref: 5445/82/0075/RA/OS

The Department of Works and Engineering within the Ministry of Public Works is inviting applications for the post of Principal Electrical Engineer.

Under the general direction of the Chief Engineer and the functional direction of the Assistant Chief Engineer/Operations, the post holder will be responsible for managing the Electrical Engineering Section within the multi-disciplinary Works and Engineering Department. The Electrical Engineering Section is responsible for the design and maintenance of all electrical and mechanical installations associated with Government buildings and industrial infrastructure, including electrical distribution, lighting systems, fire protection, security and telecommunications systems, HVAC and building energy management systems. The Electrical Engineering Section is also responsible for the design and installation of new street lighting and the administration of the Street Lighting Act.

Applicants must possess a recognized Bachelor's Degree in Electrical Engineering, or equivalent and must be a corporate member of the Bermuda Association of Professional Engineers or an equivalent professional engineering body overseas. Applicants must also have five (5) years' post professional qualification experience, and must be fully conversant with current computer languages. Applicants must also have a proven electrical power systems background or other recognized specialty including the design of medium and low voltage distribution systems, motor circuits and controls and system protection. In addition, applicants must be fully conversant in the design of lighting, fire protection, security and telecommunication systems.

Applicants should have a sound knowledge of the US National Electrical / NFPA codes or equivalent. Additionally applicants should be conversant with preparing and working within budgets.

The successful candidate will be responsible for leading and supervising professional engineers and technologists. Applicants interested in being considered for the above post **MUST complete a security vetting form (to include passport and social insurance numbers).**

This position will be offered on a three (3) year contract term. Any persons wishing to be considered for the position advertised may apply by submitting a completed Government of Bermuda application form (which can be downloaded from **www.gov.bm**) quoting the appropriate reference number, to:

the Secretary of the Public Service Commission, 3rd Floor, Ingham and Wilkinson Building, 129 Front Street, Hamilton HM12, BERMUDA; email: hr@gov.bm or by fax: 441-295-2858.

Closing date: August 5, 2011.

Carnegie Mellon ENGINEERING

Faculty Position

www.cit.cmu.edu

Carnegie Mellon University is embarking on an exciting opportunity to transform graduate education in East Africa by introducing new models of education, research and development, and the commercialization of information and communication technologies (ICT). With programs from Europe to Asia, Carnegie Mellon's College of Engineering is establishing a regional ICT Centre of Excellence (CoE) in Kigali, Rwanda that will provide first-class graduate education in a region booming with opportunities for technology innovation. Striving to become the technology hub for East Africa, Rwanda is investing heavily in infrastructure and capacity building in the critical areas of ICT and engineering.

The Programs

With a history of excellence in higher education, Carnegie Mellon will address Rwanda's and the region's skill needs by offering Master of Science degree programs in Information Technology and Electrical and Computer Engineering.

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Opportunity

Carnegie Mellon is seeking exceptional candidates who can deliver innovative, interdisciplinary graduate programs in the areas of Software Engineering, Mobile Computing, Cloud Computing, Communications, Information Security, Wireless Networking, Voice Over Internet Protocol (VoIP) Technologies, and Broadband Applications. Candidates should possess a Ph.D. in a related discipline and an outstanding record in research, teaching and leadership. Qualified candidates are expected to collaborate with local industry in technology innovation and entrepreneurship. Applications should include a comprehensive resume including a complete list of publications, 3-5 professional references, a statement of research and teaching interests (less than 2 pages each), and copies of 2 research papers (journal or conference papers).

APPLICATIONS SHOULD BE SENT TO:

Dean, College of Engineering
Carnegie Mellon University

rwanda-coe@cit.cmu.edu

http://www.cit.cmu.edu/rwanda-faculty

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Creating Value at Nanoscale

The International Iberian Nanotechnology Laboratory (www.inl.int), a recently formed International Intergovernmental Research Organisation (IGO) located in Braga, Northern Portugal, is seeking strongly motivated postdoctoral scientists to join its new research teams. Selected candidates will have the outstanding opportunity to participate in the setting up phase of the Laboratory as well as to work at the frontiers of Nanotechnology in an innovative, multicultural and multidisciplinary research organisation of about 400 people.

PD1-LL-2011 55 SELF-ORGANIZED TIO2 NANOTUBE ARRAYS (POST-DOCTORAL, ALL COUNTRIES) (1)

The successful candidate will develop TiO2 nanotube based composites and explore their applications in photoelectrochemical cells, photocatalysis and energy storage. A PhD degree in materials science & engineering/physical chemistry or a relevant field is required, as well as an adequate knowledge in electrochemistry or photochemistry and extensive hands-on experience in the electrochemical preparation of TiO2 nanotubes as well as in materials characterization techniques. DEADLINE: 31-08-2011

PD2-LL-2011 56 NANOSTRUCTURE ARRAYS FOR ENERGY STORAGE AND SENSING (POST-DOCTORAL, ALL COUNTRIES) (1)

The successful candidate will work on silicon nanowire based energy storage devices and sensors, involving a collaborative program between INL and MIT. A PhD degree in materials science & engineering/physics/physical chemistry or a relevant field is required, as well as extensive hands-on experience in metal assisted etching of Si or Si based energy storage devices. Work experience in clean room is a plus. DEADLINE: 31-08-2011

PD3-LL-2011 57 NANOMATERIALS FOR ENERGY STORAGE AND SENSING (POST-DOCTORAL, ALL COUNTRIES) (1)

The successful candidate will be responsible for developing novel (e.g. hollow or porous) nanostructures for use in high-performance Li-ion batteries and supercapacitors performance. A PhD degree in materials science & Engineering/inorganic chemistry/physical chemistry is required, as well as sufficient knowledge and extensive hands-on experience in Li-ion batteries and/or supercapacitors. Knowledge on atomic layer deposition (ALD) is a plus. DEADLINE: 31-08-2011

PD4-JG-2011 MICRO ENERGY HARVESTING (POST-DOCTORAL, ALL COUNTRIES) (2)

The INL MEMS Laboratory is looking for an experienced applicant in processing state-of-the-art PZT materials, cleanroom fabrication and testing of microsystems. The scope of this project is to develop intelligent energy harvesting MEMS devices for medical and environmental sensors. Know-how on electronics and CMOS design will be considered a plus. DEADLINE: 07-08-2011

PD5-JG-2011 LARGE-SCALE-INTEGRATED MICROELECTROMECHANICAL SYSTEMS (POST-DOCTORAL, ALL COUNTRIES) (2)

The INL MEMS Laboratory is looking for a highly skilled applicant in MEMS/NEMS technology with hands-on experience. Know-how and experience in flexible electronics processing will be considered a plus. The ideal candidate must also be proficient in instrumentation, automation of measurement setups and/or wafer-scale testing of microdevices. DEADLINE: 07-08-2011

PD6-JG-2011 SILICON-BASED BIO-MEMS (POST-DOCTORAL, ALL COUNTRIES) (2)

The INL MEMS Laboratory welcomes applicants with previous laboratory experience in developing MEMS and NEMS devices used in biomedical applications. The ideal candidate must be highly proficient in advanced silicon technologies and knowledgeable in microfluidics, biology and medicine topics. Candidates with additional know-how on electronics and hands-on experience with CMOS design will be preferred. DEADLINE: 07-08-2011.

(1) Research group led by Dr. Lifeng Liu
(2) Research group led by Dr. João Gaspar

INL welcomes applicants with an interdisciplinary research track in the above-mentioned topics and related research areas. INL will offer an exciting, and highly competitive research environment, including contract working conditions in line with those offered by other IGOs. Interested applicants should submit a cover letter, curriculum vitae, and contact details of two referees related with the candidates scientific past achievements to the INL recruitment website (www.inl.int/work-employment.php).

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Invited University Chair in Optical Communications

universidade de aveiro · Nokia Siemens Networks

The UNIVERSIDADE DE AVEIRO (UA) and NOKIA SIEMENS NETWORKS PORTUGAL S.A. (NSN), with Foundation for Science and Technology (FCT) cosponsoring, announce an international public call for the attribution of an Invited Research Chair in Telecommunications field.

The primary goal of the NSN Invited Chair is to attract to Portugal a top level researcher currently working abroad, in order to develop and to promote emerging areas of knowledge, namely fostering the growth of research and development activities, and advanced education in fields of common interest both to the UA and to NSN. UA will be the host institution, with special focus one of the following knowledge areas:

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- High Speed Optical Communications for Access and Core Networks

MAIN PURPOSE OF THE ROLE AND KEY RESPONSIBILITIES

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The Invited Chair will have the responsibility to:

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- To develop advanced education courses and programmes in related fields, namely at the doctorate and post-doctorate levels;

Researchers who are not available for a full-time contract will be considered as long as they can spend at least half of their time in Aveiro. The maximum amount of the financial incentive is 75.000 € gross per year.

APPLICATIONS AND DEADLINES

Applications should be submitted to: Professor José Fernando Ferreira Mendes; jfmendes@ua.pt

Applications shall include:

- *Curriculum vitae* (detailed);
- Proposed 3 years activity programme;
- Letter of motivation

The evaluation of candidates will begin on 5th of September 2011 and will continue until the position is filled.

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(2)*Antenna and microwave electronic*

Design and fabrication of new antennas and microwave circuits (amplifier, coupler, phase shifter, ...) based on LTCC technology. An application of these future devices is the development of a smart antenna for wireless communications.

The candidate must have a PhD, an outstanding research record, including several publications and strong English language skills. The research group is looking for team players, capable of supervising PhD and master degree students. There are no teaching duties associated with this position. Being able to communicate in French is an asset but not mandatory.

We view the potential of wireless communications in all areas of activity as virtually limitless. By gathering a team of very competent and creative researchers along with a set of inspired industry partners, prof. François Gagnon Eng., Ph. D. Chair holder is constantly demonstrating that radio communication potential is far from being exhausted

For further information visit us at chaireultra.etsmtl.ca or, to apply, send us an email at info@comunite.ca

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IEEE

The Department of Electrical and Computer Engineering at The Ohio State University invites faculty applications in the area of terahertz sensing. Successful candidates will be expected to develop a vigorous externally-funded research program, show leadership and excellence in academic and scholarly activities, and demonstrate a commitment to excellent teaching at the undergraduate and graduate levels. The Ohio State University is an affirmative action, equal opportunity employer. For further details on this position, visit

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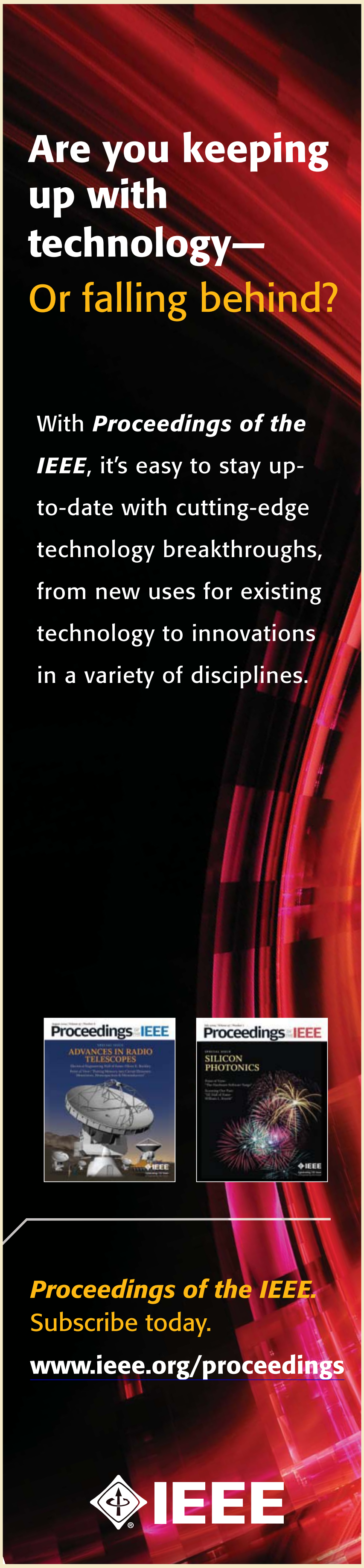


THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

The Hong Kong Polytechnic University is the largest government-funded tertiary institution in Hong Kong in terms of student number. It offers programmes at Doctorate, Master's, Bachelor's degrees and Higher Diploma levels. It has a full-time academic staff strength of around 1,200. The total consolidated expenditure budget of the University is in excess of HK$4 billion per year.

DEPARTMENT OF ELECTRICAL ENGINEERING

The Department of Electrical Engineering is one of the five academic units in the Faculty of Engineering. It is the major education provider in electric power engineering and utilisation of electric power among the universities in Hong Kong. The Department is playing an important role in educating the electrical engineers for Hong Kong, and to some extent for the Chinese mainland arising from its continuous expansion in the electrical infrastructure. Please visit the website at http://www.ee.polyu.edu.hk for more information about the Department.

(1) Professor / Associate Professor in Power Systems (two posts)
(2) Associate Professor in Transportation Systems Engineering (two posts)
(3) Associate Professor in Utilisation

The appointees will be required to (a) provide leadership in research, programme/curriculum development and administration; (b) teach at undergraduate and postgraduate levels; (c) conduct research that leads to publications in top-tier refereed journals and awards of research grants; (d) supervise student projects and theses; and (e) engage in scholarly research/consultancy in at least two of the following areas for post (1): (i) new technologies and algorithms in smart grid applications, (ii) renewable energy and sustainable development, (iii) power system stability planning and control, (iv) power quality and protection, and (v) computational intelligence in power and energy system; or for post (2) in transportation/railway engineering: (i) operations & management, (ii) system modelling & analysis, (iii) traffic control, (iv) asset management, maintenance, risk & reliability analysis of relevant systems, (v) signalling, and (vi) electromagnetic interference & compatibility studies; or for post (3): (i) condition monitoring of electrical systems, (ii) energy harvesting, (iii) electrical vehicle and fast battery chargers, and (iv) electrical machines and drives.

Applicants should have (a) a PhD in a relevant discipline plus substantial years of relevant experience in teaching, research and industry; (b) excellent teaching and publication records; (c) a good network with international researchers to contribute to the development of high-level applied research collaborations between PolyU and reputable organizations; (d) experience in securing or raising research funds from the government or industry; and (e) excellent communication skills and the ability to use English as the medium of instruction.

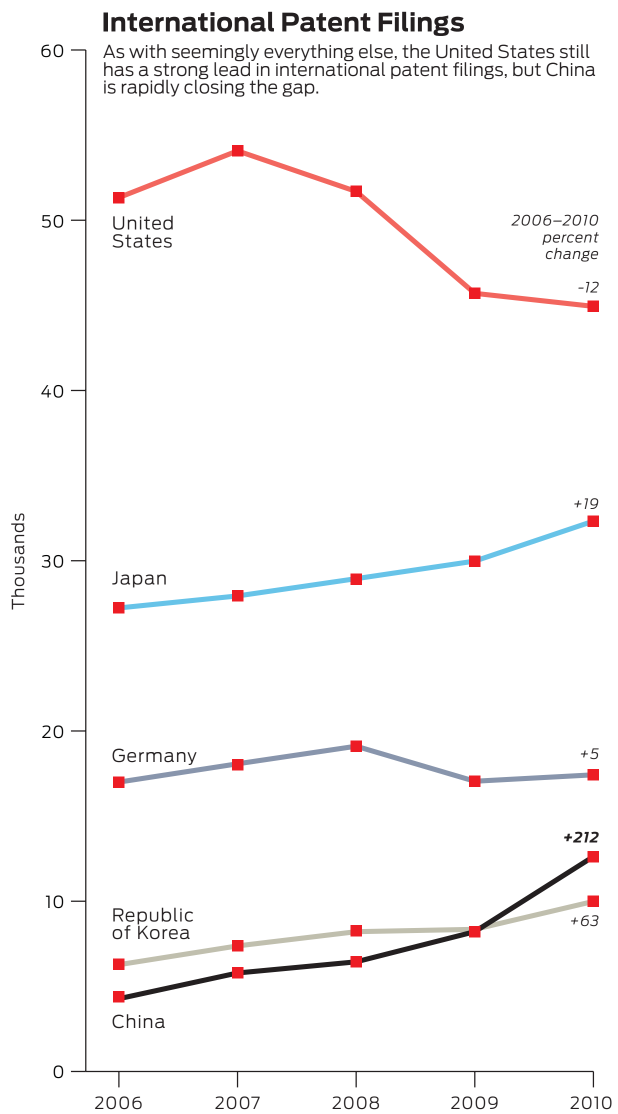
For post (1), candidates with less experience will be considered for appointment at the level of Associate Professor.

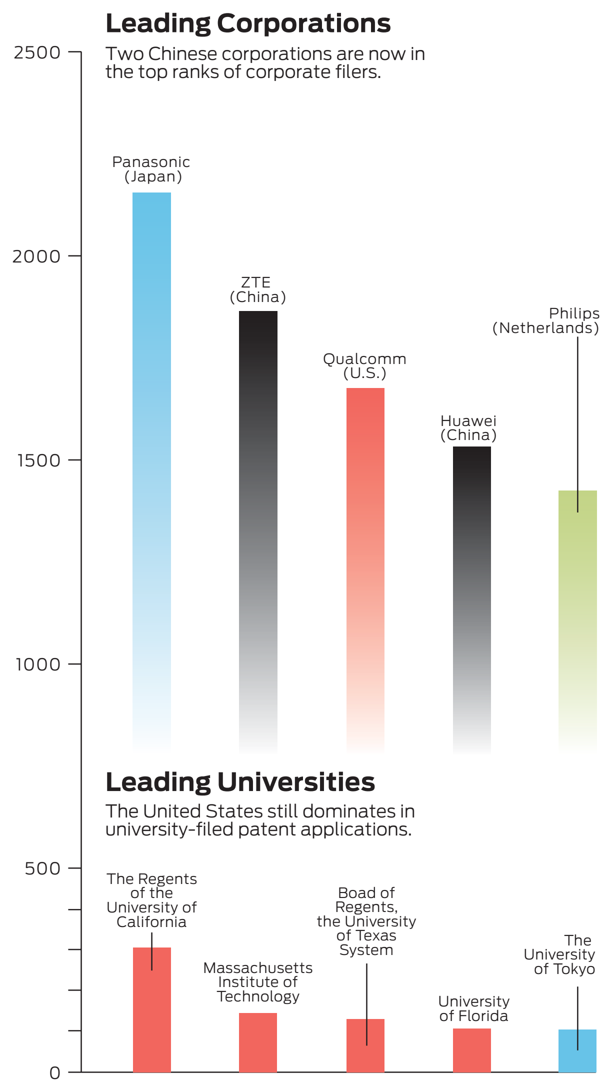
Remuneration and Conditions of Service
Salary offered will be commensurate with qualifications and experience. Initial appointments will be made on a fixed-term gratuity-bearing contract. Re-engagement thereafter is subject to mutual agreement. Remuneration package will be highly competitive. Applicants should state their current and expected salary in the application.

Application
Please submit application form via email to hrstaff@polyu.edu.hk; by fax at (852) 2364 2166; or by mail to **Human Resources Office, 13/F, Li Ka Shing Tower, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong**. If you would like to provide a separate curriculum vitae, please still complete the application form which will help speed up the recruitment process. Application forms can be obtained via the above channels or downloaded from http://www.polyu.edu.hk/hro/job.htm. ***Recruitment will continue until the positions are filled.*** Details of the University's Personal Information Collection Statement for recruitment can be found at http://www.polyu.edu.hk/hro/jobpics.htm.

For further details about the University, please visit www.polyu.edu.hk

the data





Source: World Intellectual Property Organization

China Rising: International Patent Applications

SUPERCOMPUTING POWER, kilometers of high-speed rail, planned nuclear power plants—this page has had a definite Sino theme lately. Here's another measure of China's tech growth: international patent applications. In 2010, China filed 56 percent more international patent applications than the year before. The number of U.S. applications, by contrast, was down for a third year in a row.

The figures come from the World Intellectual Property Organization, a United Nations agency based in Geneva. An international application is the first step toward claiming ownership in 142 nations—a domestic patent protects an invention only in one country.

Despite China's growth, the United States still tops the list by a wide margin, accounting for more than a quarter of all applications last year. China's rise, though, is signaled by having two manufacturers in the top ranks of individual corporations: ZTE Corp. and Huawei Technologies Co. That both are in digital communications is no coincidence—that area leads the list of industrial sectors and features another patent powerhouse, Qualcomm.

The United States also still dominates the list of leading university applicants. The University of California system and MIT are at the top, but the roster also includes the University of Florida, in Gainesville, which received US $678 million in research awards in 2010 and is building a new "super incubator." Staff there will work to commercialize medical and clean energy technologies. The Sunshine State's innovations may soon go beyond Gatorade. *—Joseph Calamia*

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