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SUPERCONDUCTIVITY'S FIRST CENTURY

SUPERSTRONG MAGNETS ARE NICE, BUT WHAT'S NEXT?

REPACKAGING THE CHIP

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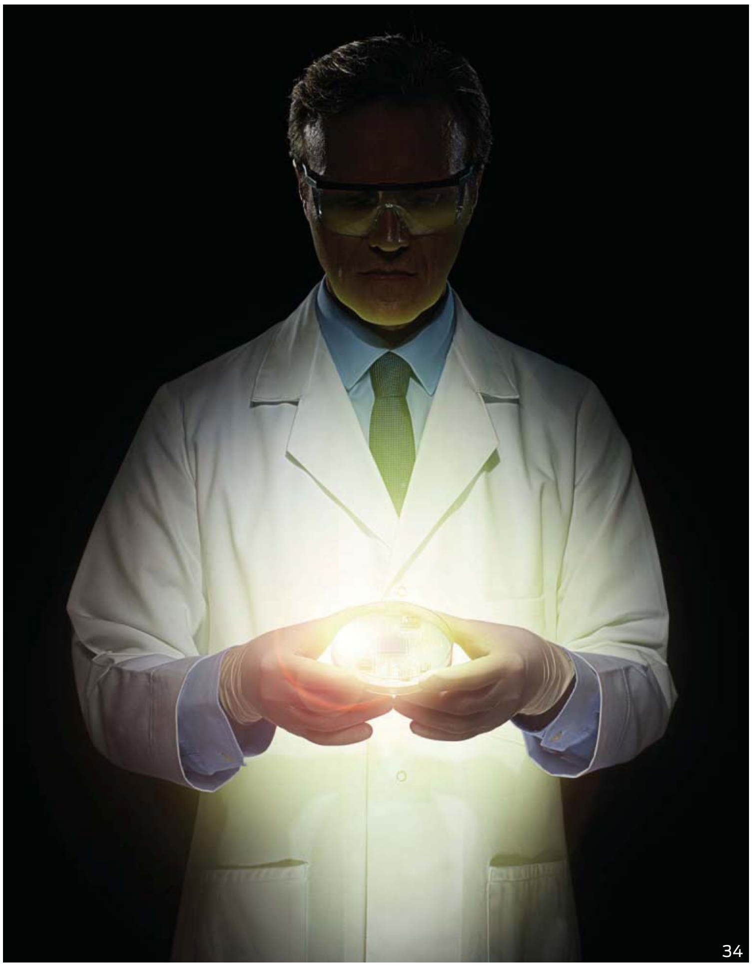
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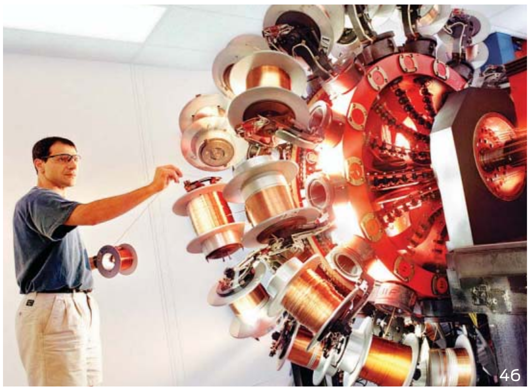
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COVER: ANATOMY BLUE
THIS PAGE, TOP: PHOTO, DAN SAELINGER; PROP STYLIST, LAURIE RAAB/HALLEY RESOURCES; MAKEUP AND HAIR STYLIST, GREG CLARK/HALLEY RESOURCES; TOP RIGHT: BIBLIOTHÈQUE NATIONALE DE FRANCE; BOTTOM RIGHT: PETER GINTER/GETTY IMAGES


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OPINION

DEPARTMENTS

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back story

For the Love of Olives

In the late 1980s, while developing the accounting software that would become QuickBooks, Ridgely Evers took a little hiatus in Italy. His goal: to reverse engineer his favorite olive oil. He traced it to an 800-year-old grove of olive trees in Tuscany.

Some 4500 descendants of those trees now thrive on Evers's farm in Sonoma County, Calif., where *IEEE Spectrum* Senior Editor Tekla S. Perry [above] visited him last fall, winding down a one-lane road flanked by a stone wall, past a pond where egrets wade to the house Evers built himself. Showing her around the 28-hectare farm in his Prius, he told Perry, "The trees love it here. They love the soil. They love the climate." And Evers clearly loves his trees.

The olives from those trees produce an amazing olive oil, smooth to taste, then peppery at the back of the throat. In 1997 that oil won a blind tasting in Italy, the first American olive oil ever to do so. Evers calls his oil DaVero, which comes from *davvero*, an Italian word that translates as "indeed" but is used around food to mean, loosely speaking, "yum."

Today DaVero produces between 900 and 2000 cases of oil annually. On his farm, Evers also grows Sangiovese and Sagrantino grapes for wine, Meyer lemons that go into a lemon-infused oil, as well as lavender, apples, and various vegetables. They're all sold in a roadside tasting room that Evers built himself; he sells the oil and the wine online. Itinerant beekeepers provide an annual crop of estate honey. Make no mistake—this is a working farm, not a hobby.

But Evers hasn't walked away from technology. He balances his decidedly low-tech farming operation with consulting and is once again creating software for the small-business market, described in "From QuickBooks to Slow Food," in this issue. ❑

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 Reflections column is in *IEEE Spectrum*, Vol. 48, no. 3 (INT), March 2011, p. 25, or in *IEEE Spectrum*, Vol. 48, no. 3 (NA), March 2011, p. 29.

RIDGELY EVERS

contributors

PUSHKAR APTE, W.R. BOTTOMS, WILLIAM CHEN, and **GEORGE SCALISE** worked on the International Technology Roadmap for Semiconductors, which among other things covers future packaging technology, the focus of "Good Things in Small Packages" [p. 40]. Apte, now a consultant, was vice president of technology at the Semiconductor Industry Association, where Scalise was president before retiring this year. Bottoms, with over 30 years in the industry, was most recently chairman of Third Millennium Test Solutions. Chen, a three-decade IBMer, is now a fellow for the ASE Group.

ARIEL BLEICHER, a recent graduate of New York University's science reporting program, has written, online, for *The Scientist* and *OnEarth*, and for the *Anchorage Press*. While in Paris researching this month's feature on the French National Library's Web archives [p. 26], she found the library's wealth of books, magazines, and diverse ephemera impressive, as well as its fleet of robotic helpers—each "the shape of a really big cheese wheel," she says—which shuttle books from stacks to waiting patrons.

SASWATO R. DAS, author of the Update story on spintronic advances [p. 17], contributes frequently to *IEEE Spectrum*. For one assignment, he interviewed science fiction writer Arthur C. Clarke. That 2008 interview turned out to be the futurist's last. "He was in poor health, but his mind was still very sharp," Das says. Based in New York City, Das has written for *The Economist*, *Scientific American*, and *New Scientist*.

PRADEEP HALDAR and **PIER ABETTI,** who wrote "Superconductivity's First Century" [p. 46], together have almost a half century of experience with superconductivity. Haldar, an IEEE Senior Member, is a professor of nanoengineering at the University of Albany, of the State University of New York. Abetti, an IEEE Life Fellow and professor of enterprise management at Rensselaer Polytechnic Institute, once had Haldar as a student. Only after Abetti began lecturing about the commercialization of superconductivity did he learn that Haldar had been a director of technology in that very industry. "He made me get up and talk about the whole thing," says Haldar.

JULIUS B. LUCKS and **ADAM P. ARKIN** write about how to make genetic engineering more like electrical engineering in "The Hunt for the Biological Transistor" [p. 34]. Arkin is a professor of bioengineering at the University of California, Berkeley. Lucks, currently a postdoctoral fellow at UC Berkeley, will be joining the chemical engineering faculty at Cornell. Although trained in chemistry, Lucks has done plenty of Python coding, and Arkin's hacking goes all the way "back to the days when they had Heathkit stores and Radio Shack had stuff you could actually use," he says.

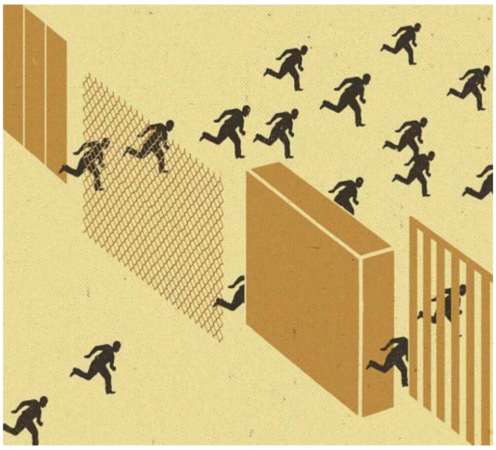
CHRISTIAN NORTHEAST, a Canadian illustrator, created the image for Reflections [p. 25]. In 2009, Northeast published his book, *Prayer Requested,* in which he depicts heavenly requests for both good health and uilleann bagpipes. His clients have included *The New Yorker, Rolling Stone, Playboy,* and Nickelodeon.

CLOCKWISE FROM TOP LEFT: CAROLINE ORCUTT; CHRISTIAN NORTHEAST; SUMANA RAYCHAUDHURI


Name
Dr. Laurel Watts
Job Title
Principal Software Engineer
Area of Expertise
Chemical Engineering
LabVIEW Helped Me
Control multiple instruments operating in harsh conditions
Latest Project
Engineer the ultimate storm chaser
NI LabVIEW
LabVIEW makes me better because the
INTEGRATION
with hardware is so seamless

spectral lines

The Virtual Fence's Long Good-bye



SEVERAL YEARS ago, I wrote in my blog for *IEEE Spectrum* that the U.S. Department of Homeland Security's Secure Border Initiative's SBInet, the "virtual fence" project that was supposed to build a sensor-, radar-, and camera-arrayed fence along the U.S.–Mexico border, was finished, kaput. It wasn't a matter of whether the project was going to be terminated, only when and at what final cost.

Well, finally, this January DHS Secretary Janet Napolitano announced the termination of the project, long dead but still on life support. The obituary came after yet another US $230 million or so had been spent. To make matters worse, it was spent over the same time period that an internal DHS and Customs and Border Protection (CBP) review team was conducting a reassessment of the program, one that "incorporated an independent, quantitative, science-based 'Analysis of Alternatives' to determine if SBInet is the most efficient, effective and economical way to meet our nation's border security needs."

Now, with more than $1 billion spent on SBInet since 2006, here's what the review team's "Report on the Assessment of the Secure Border Initiative-Network (SBInet) Program" had to say:

> *[T]he department has concluded the SBInet program, as originally proposed, does not meet current standards for viability and cost-effectiveness. While it has generated some advances in technology that have improved border patrol agents' ability to detect, identify, deter and respond to threats along the border, SBInet does not and cannot provide a single technological solution to border security.*

Have no fear, though. From the same report:

> *As a result, Secretary Napolitano has directed CBP to end SBInet as originally conceived and instead use existing, proven technology solutions tailored to the distinct terrain and population density of each border region.*

But for those of you who remember, SBInet was said from the start to be a technologically low-risk project based on existing, proven technology solutions, according to both the prime contractor—Boeing—and the DHS.

But as I noted in 2007, their approach was akin to me saying that I was going to build a car using a Honda Accord engine, a Ford F-150 chassis, a GM Saturn Vue interior, et cetera, and then claiming that the resulting effort would be low risk. It might make sense to me in the middle of a sleepless night, but what about all those tenacious little issues of integration?

So what will happen next? Well, a sort of "Son of SBInet" is looming on the horizon. The report continues:

> *DHS is currently developing a comprehensive border technology deployment plan that will build upon successful technology currently deployed and provide the optimum mix of proven surveillance technologies by sector. Where appropriate, this technology plan will also include elements of the former SBInet program that have proven successful.*

This "new way forward," the DHS says, "is expected to cost *less* than $750 million and will cover the rest of the Arizona/Mexico border—totaling 323 miles." SBInet I, at over $1 billion, managed to cover only 53 miles (85 kilometers).

It will take a while before Son of SBInet is deployed, because the DHS plans to hold an open competition to acquire all the technologies needed. In a recent solicitation document, the government states that it desires technology solutions that are "complete, fully integrated, and proven commercial-off-the-shelf/government-off-the-shelf (COTS/GOTS) solutions," which can be integrated without "measurable development effort" and are "open architecture" in design. The government also wants to procure the above technology using fixed price contracts.

Does anyone really want to bet that the "expected" cost and the final cost of Son of SBInet will turn out to be *less* than $750 million? —ROBERT N. CHARETTE

Robert N. Charette is president of the consulting company ITABHI Corp. and a contributing editor for IEEE Spectrum.

This article is based on several posts that appeared earlier this year in Charette's IEEE Spectrum *blog, The Risk Factor.*

DAN PAGE

Corrections

In "Batteries That Breathe" (Update, February 2011), the storage capabilities of lithium-ion batteries and lithium-air technology were incorrectly characterized. The numbers provided were capacities, not current densities. In addition, lithium-ion batteries typically can handle about 1000 charge/discharge cycles.

In "The Tops in Flops" (February), in the graphic "Number Crunching," we listed the operators of the ASCI White and the BlueGene/L supercomputers incorrectly. According to the Top500 (http://www.top500.org), Lawrence Livermore National Laboratory should be credited for making the ASCI White the world's top-ranking supercomputer in 2000; IBM and the U.S. Department of Energy for the BlueGene/L in 2004; and the U.S. Department of Energy, the National Nuclear Security Administration, and the Lawrence Livermore National Laboratory for the BlueGene/L supercomputers of 2005 and 2007.

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AT THE FRONTIERS OF SIMULATION
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update

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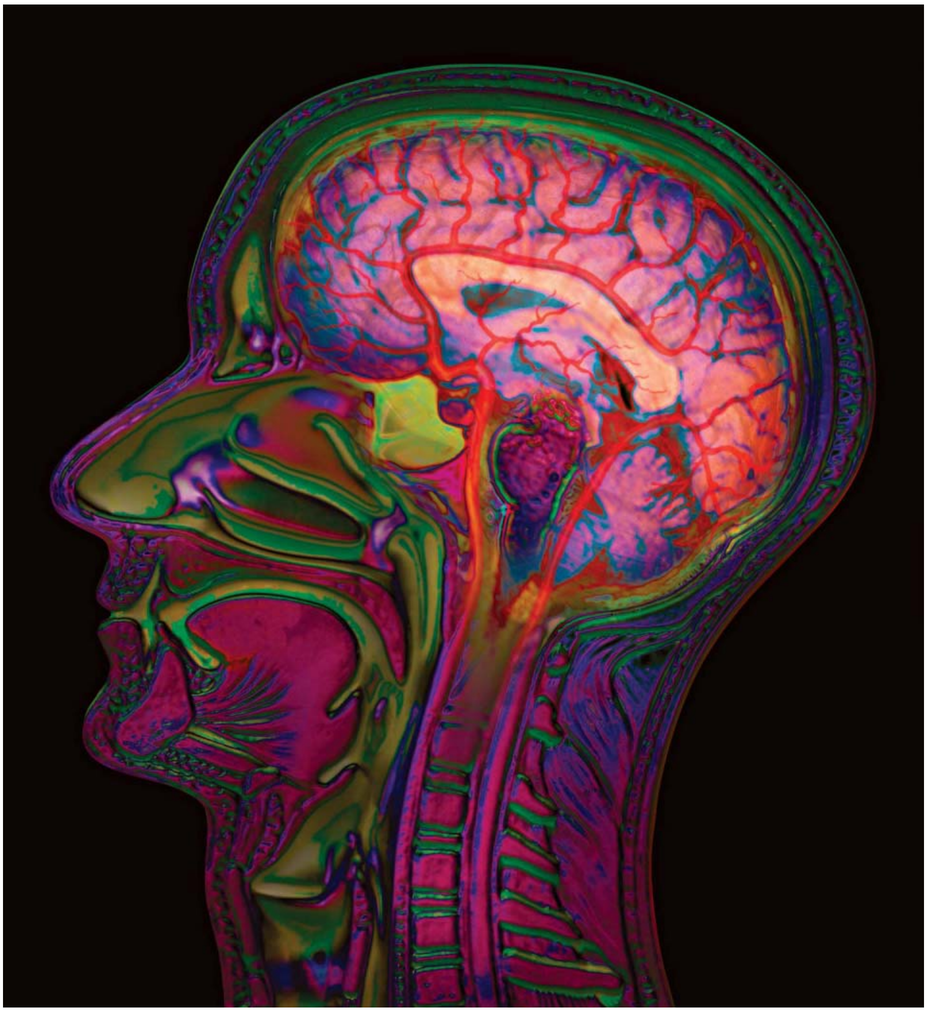
The Psychiatrist in the Machine

Software rivals doctors at distinguishing among different kinds of depression and schizophrenia



HARD EVIDENCE: Psychiatrists want to diagnose patients based on their physiology rather than subjective symptoms. Images of the brain and the electric signals that emanate from it could be key to picking the right treatments for depression and schizophrenia.
PHOTO: DON FARRALL/GETTY IMAGES

PSYCHIATRISTS MAKE life-altering decisions on the basis of a subjective assessment of a set of symptoms. But many freely admit they have far too little information to answer some critical questions: Is the patient suffering from severe depression, or is this a case of bipolar disorder that hasn't fully manifested itself yet? Will this schizophrenic patient respond to this drug? Draw the wrong conclusions about a depressed patient and the treatment may send him careening into mania. Make the wrong assessment of a schizophrenic person and you may give him an ineffective drug whose side effects could kill him.

"I make these decisions every day," says Dr. Gary Hasey, associate professor of psychiatry at McMaster University, in Hamilton, Ont., Canada. "If you make an error, you stand a good chance of making things worse."

Today's method of choosing treatment—essentially an informed version of trial and error—costs an extra US $8500 per patient per year for the most difficult-to-treat depression patients in the United States. What's worse, it can eat up years of a patient's life with fruitless drug therapy, sullied with side effects.

Hasey is among a growing group of psychiatrists pushing for a better way to make those decisions, by using physiological signals that include electrical, functional, and structural data gleaned directly from their patients' brains via electroencephalogram (EEG) and magnetic resonance imaging (MRI).

With McMaster electrical engineering professor James Reilly and other colleagues, Hasey has been testing software that sifts through schizophrenia patients' EEGs to find signs that show whether or not they will respond to clozapine, the "drug of last resort." Other algorithms they have developed can automatically sort people—with an 85 percent success rate—according to whether they suffer from depression, bipolar disorder, schizophrenia, or are free of mind or mood problems. And the group is also developing a system that predicts which of the many available treatments would be most effective for a patient suffering from major depression.

The McMaster group is not alone. Engineers and physicians in the United States and Europe

update

are using MRI brain scans to diagnose schizophrenia and other conditions. And a start-up firm, CNS Response, in Aliso Viejo, Calif., has completed clinical trials of an EEG-based system to aid psychiatrists in predicting which type of depression medication a patient will respond to.

Doctors working with CNS Response recently reported that its EEG-analysis system could predict, with 65 percent accuracy, whether depression patients who had not improved with at least one drug treatment would respond to the next drug tried. Sixty-five percent might not seem like good odds, but it's a big improvement over the best practices uncovered in a landmark seven-year study, called Sequenced Treatment Alternatives to Relieve Depression. "STAR*D was a high-water mark for serial trial and error," says George Carpenter, CEO of CNS Response. "But it wasn't very high."

At its heart, his company's system, called referenced EEG, is a large, anonymized database of EEGs from both healthy and mentally ill people. The records included the patients' treatment histories—what worked and what didn't. When a doctor uses the system on a patient, the patient's EEG is correlated with the collected data using statistical regression methods. The system then generates a list of treatment options and their degree of success in patients with similar EEG features. In the clinical trial, reported in the January issue of *Journal of Psychiatric Research*, Carpenter says that with the system's advice, doctors "doubled the chances of getting it right" versus the practices laid out in the STAR*D trial.

According to Carpenter, one of the ways the company hopes to improve on those odds is to move to a machine-learning algorithm, one in which the system is trained on the EEG database to pick out the few really important EEG variables rather than comparing the more than 1000 it deals with now.

"Essentially, we have the makings of a virtual psychiatrist"

DR. GARY HASEY, ASSOCIATE PROFESSOR OF PSYCHIATRY, MCMASTER UNIVERSITY, HAMILTON, ONT., CANADA

That teaching process is the crux of the recent MRI research, and it's just what the software developed at McMaster does using EEG. "What we've done is taken 10 000 features and reduced it down to about 5 or 10," says McMaster's Reilly, who presented the team's research at the IEEE Engineering in Medicine and Biology Society conference last September. Reilly and his colleagues trained two software programs to pick out critical features. One learned to predict the success of depression treatment options with 80 to 85 percent accuracy. The other determined with up to 89 percent accuracy whether or not a schizophrenia patient would respond to the dangerous but effective drug clozapine.

Researchers led by University of New Mexico electrical and computer engineering professor Vince D. Calhoun are hoping to reach end results similar to those of the McMaster group. With IEEE Fellow Tülay Adali at the University of Maryland, Baltimore County, and associate professor of electrical engineering Juan I. Arribas at the University of Valladolid, Spain, he has been developing a machine-learning system that can distinguish between people with schizophrenia and those with bipolar disorder on the basis of functional MRI brain scans. The hope is that such a system would give doctors a head start on treatment, because it can be difficult to tell the difference between the two conditions the first time a patient is seen.

An fMRI scan shows not just the overall structure of the brain but also indicates which parts are active at any time, according to changes in the blood flow to them. Using fMRI data, the system automatically finds brain regions whose activity seems relevant to the diagnosis. It was able to sort bipolar, schizophrenic, and healthy brains with about 70 percent confidence. (It can perform a two-way sort—distinguishing bipolar from schizophrenic, for instance—with 90 percent confidence, but that's an easier problem.) Calhoun and his colleagues presented the workings of the system in the December 2010 issue of *IEEE Transactions on Biomedical Engineering*.

Researchers at Harvard Medical School are using the newest flavor of MRI for diagnosis. Called diffusion MRI, or diffusion tensor imaging, it shows how water flows inside the tiny neuronal fibers within the brain. That flow allows the mapping of connections between the brain's regions. With fMRI you are measuring "the symptoms side of things," says Yogesh Rathi, an assistant professor and leader of the dMRI team at Harvard Medical School. "We want to know the anatomy."

That could be important, because although the brain function of medicated patients may be altered in a way that would make diagnosis difficult, it's unlikely that their anatomy would change.

The Harvard system was able to correctly pick out schizophrenic patients 90 percent of the time, according to research presented at the 2010 IEEE Symposium on Biological Imaging. "Our end goal," says Rathi, "is to diagnose as soon as possible—even try to predict."

Researchers believe these systems could get so good at diagnosis that they could act as advisers to primary care physicians, says McMaster's Hasey. That's important in places where access to an expert is limited. "Essentially, we have the makings of a virtual psychiatrist," he says.

—SAMUEL K. MOORE

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295 EXABYTES Amount of data humanity could store electronically in 2007, according to University of Southern California researchers.

SEVERN ESTUARY, United Kingdom

tech in sight

Tides Turn for Tidal

Big tidal power projects seek backing

Capricious air currents and passing clouds may thwart wind and solar power, but the tides, governed by the gravitational pull of the moon and the sun, might prove a more dependable energy source. In certain spots, the tides have already proved a good source of electricity. La Rance Tidal Power Station—a barrage on the Rance River's estuary in Brittany, France—has converted the tides' movements into as much as 240 megawatts of electricity since 1966. But support for new projects is less predictable: Backing has ebbed for some designs, while for others it's just starting to flow.

—Joseph Calamia

INDIA'S GULF OF KUTCH

Atlantis Resources Corp., based in Singapore and London, is building big. Its AK-1000 tidal power turbine, the largest of its kind, weighs 1300 metric tons, has rotors with an 18-meter diameter, and stands 22.5 meters high. The giant can generate up to 1 MW of power and has two rotors per generator to collect energy from water flowing in either direction. Although that's a mere fraction of what some barrages can produce, Atlantis CEO Timothy Cornelius says that turbines allow funders to test the waters, one generator at a time. "The big difference between a La Rance and our turbines is that you build up capacity incrementally," he says. "It allows governments to get comfortable..... You don't just go from 0 to 240 MW." The company started testing the turbine at the European Marine Energy Centre in Orkney, Scotland, this past August; it already has interested buyers. In January 2011, Atlantis announced that Narendra Modi, the chief minister of Gujarat, India, approved a partnership for a 50-MW tidal power project in the Gulf of Kutch. Cornelius expects that construction will likely begin in 2012 and finish in 2013—making the company's turbines contenders for Asia's first commercial-scale tidal power station.

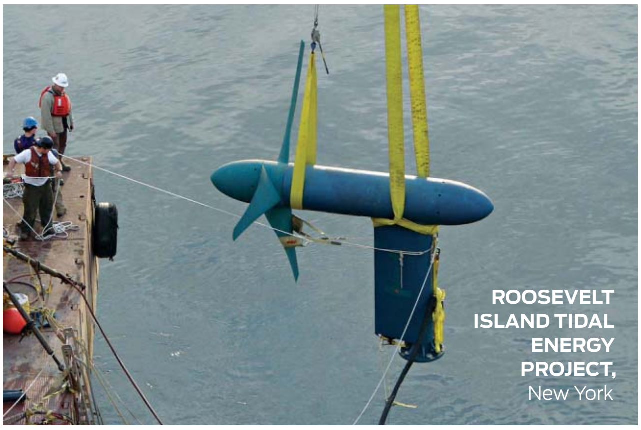
ROOSEVELT ISLAND TIDAL ENERGY PROJECT

As part of its Roosevelt Island Tidal Energy Project, Verdant Power, headquartered in New York City, sank its first three-bladed turbines into the East River in 2002. From 2006 to 2008, a set of five turbines—which could passively pivot to face the tidal currents—delivered a total of 80 megawatt-hours of electricity to a supermarket and parking garage on the city's Roosevelt Island. By the end of 2014, Verdant Power plans to install 30 of its newest turbines on triangular frames in the river. Each can produce 35 kilowatts, for a total peak power output of around 1 MW. More power could come from placing larger, 500-kW generators in other, deeper waters like the Long Island Sound or from using the turbines to tap river currents in addition to tidal currents, says Trey Taylor, cofounder and president of the company. Verdant Power has also launched a project in Canada's St. Lawrence River.

SEVERN ESTUARY

Stretching from the banks of Lavernock Point in Wales to the English shores of Brean Down, a 15-kilometer barrage across the Severn Estuary could meet up to 5 percent of the United Kingdom's electricity demand, its developers at Corlan Hafren say. The barrage would make use of Severn's 14-meter difference in water depth between low and high tides. Gates would close at high tide to trap water behind the barrage. Then, when the tides turn, the water would return at high pressure through the barrage's turbines to generate an estimated peak power of 8 gigawatts.

A UK Department of Energy and Climate Change feasibility study, released in October 2010, dashed hopes for public funding of the barrage's construction, questioning whether the costs of the project were too high, measured both in pounds sterling (which the report estimated at up to £34 billion) and its impacts on neighboring nature conservation sites. But Corlan Hafren hasn't given up: Now it is looking for private investors to front what it estimates will be £23 billion for construction.



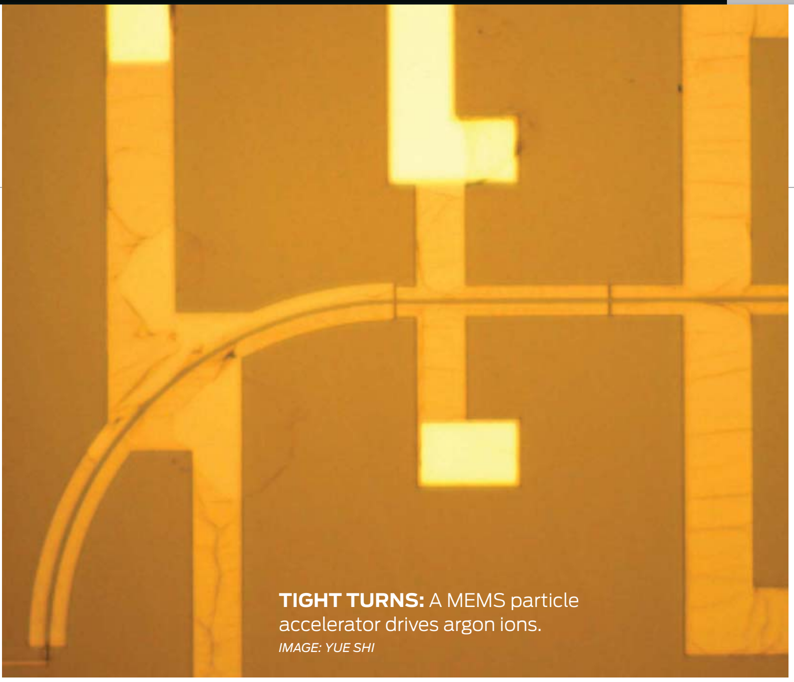
ROOSEVELT ISLAND TIDAL ENERGY PROJECT, New York

GULF OF KUTCH, India

CLOCKWISE FROM TOP: CORLAN HAFREN; ATLANTIS RESOURCES CORP.; KRIS UNGER/VERDANT POWER update

A Chip-Scale Particle Accelerator

Zipping ions down a MEMS racetrack could lead to portable particle beams



TIGHT TURNS: A MEMS particle accelerator drives argon ions.
IMAGE: YUE SHI

Forget for a moment about the quest to build bigger high-energy particle accelerators. At the IEEE MEMS 2011 conference in January, researchers instead explained their efforts to create a smaller one.

Their chip-size cyclotron can guide argon ions with around 1.5 kiloelectronvolts of energy down a 5-millimeter accelerating track before whipping them around a 90-degree turn. The system boosts the ions' energy by 30 electronvolts. That's certainly not a world record; the Large Hadron Collider, the biggest and most powerful particle pusher in the world, would have it beat by some seven to 10 orders of magnitude. But unlike its larger cousins, this accelerator has no need for bulky magnets.

Instead it uses electric fields set up along electrode guide rails to accelerate and steer its particle beam. The device's designers at Cornell University, in Ithaca, N.Y., say that with more research, similar electrostatic mini-accelerators might be used in shoebox-size scanning electron microscopes or portable particle-ray guns for cancer treatment.

Funded by the U.S. Defense Advanced Research Projects Agency, Yue Shi, an electrical and computer engineering graduate student developed the accelerator-on-a-chip. She is working to create both a device that might accelerate ions to energies of hundreds of kiloelectronvolts on a chip not much bigger than a few square centimeters and a device capable of accelerating ions to hundreds of megaelectronvolts in a box the size of a suitcase.

Shi constructed three versions of the accelerator—two on silicon-on-insulator chips and one on a printed circuit board. Each had a straight, segmented acceleration track and either a 1-, 2-, or 4-mm turning radius. To test the design, she fired a stream of argon ions with around 1.5 keV of energy from a commercial ion source into each chip's tracks. Electric fields between four segments in each chip's acceleration track gave the ions a strong kick before they raced into the turn. Then another electric potential between two electrode curbs pulled ions around the bend.

If a small accelerator based on this design could bestow 1 MeV of energy to ion beams, it would have a broad range of applications, says Amit Lal, who worked with Shi and leads Cornell's SonicMEMS Laboratory.

Doctors already use particle beams to combat cancer. Such therapy requires devices that take up an entire room, but tiny accelerators might make treatments more feasible for smaller clinics or allow more localized beams to irradiate fewer healthy cells, says Lal. "Think of a scalpel with a proton beam coming out of it," he says.

Developing this proof-of-concept device into a commercial tool will take some work. Shi points out that the fastest ions that coursed through the accelerator during this initial research only had around 2 keV of energy, and that's three orders of magnitude lower than what she seeks. Having now shown that the ions can execute tight turns, Shi believes that future designs could navigate the ions repeatedly through accelerating strips to reach at least 1 MeV.

The Cornell device is not the only mini-accelerator in development, or even the smallest. Instead of electrostatics, Gil Travish, who is developing a micro-accelerator platform at the University of California, Los Angeles, wants to use the electric fields in laser light to speed particles on their way. Travish's group is starting to build a device that he describes as a 1-µm-thick "sandwich" with two mirrors above and below a gap that's only one wavelength of light high and several hundred wavelengths wide. As the light from a laser oscillates in that gap, an electron passing through the peak electric field will receive a tremendous boost—around a gigaelectronvolt per meter or a megaelectronvolt per millimeter. His team hopes to start beam tests in a prototype device in the next six months.

The UCLA team imagines that their particle beam might also one day appear in medical devices or in unmanned aerial vehicles that could examine suspicious buildings using X-rays. "I think that in the next half decade you'll start to see a real awakening," Travish says about the possibilities in particle accelerators' new realm. —Joseph Calamia

A version of this article appeared on http://spectrum.ieee.org in January.

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ADVERTORIAL


Okinawa Convention Center

Meet in Okinawa, Japan — Gateway to East Asia

Jane Ambrose asks organiser Mr. Bob Heile for some facts and figures.

The IEEE 802 Wireless Interim Session will be held from September 18-23 in Okinawa, Japan, and will encompass the IEEE 802.11 and 802.15 Working Groups. Sometimes known as the gateway to East Asia, as one of the country's most beautiful areas the Prefecture is made up of 160 sub-tropical islands which stretch between the Pacific Ocean and the East China Sea with around 50 actually being inhabited. Why choose this area for the conference? Well apart from the Okinawa Convention Center, which is located at Ginowan, just 10 kilometers North of Naha which is the capital of Okinawa, offering an extremely competitive package rate, organiser Bob Heile points to the location which also attracted him. He says: "It is really a stunning part of Japan and is particularly interesting from both a cultural and historical viewpoint."


Sesoko Beach

Mr. Heile, who is Chairman and CEO of ZigBee Alliance, a 400 member global organization which is devoted to developing standards for wireless sensor networks and is also the Chair of IEEE 802.15 Working Group as well as being Co-Chair of the Communications Task Force of IEEE P2030 on SmartGrids says that the relevance of Japan to the actual theme of the conference is also a factor and he continues: "Japanese companies, research institutions and industry groups have always been proactive in the 802 Wireless Working Groups and we do like to hold at least one meeting a year in Asia."

Mr. Heile was particularly inspired by the culture of the Okinawa area which is also known as 'Ryukyu' a name which comes from the Ryukyu dynasty which ruled the region in the 15th century. He says: "These traditions seem to be different from any others in Japan and it would be particularly suitable I think to experience, for example, the 'Eisa' dance at one of our receptions. I understand that this dance is often performed during the summer festival which will still be on in September when we are there."


'Eisa' dance

Okinawa does have a very different cultural life to the rest of Japan and the people here have experienced real hardship at times. This has led to the Okinawa residents keeping the saying 'life is a treasure' very close to their hearts and they display a 'sanshin' musical instrument in their homes instead of the sword which is traditional elsewhere in Japan. Okinawa is also known as the 'island of song and dance'. Other major festivals include the Naha Great Tug-of-War which is held to ensure a good harvest, the Okinawa International Orchid Show, the Ie Island Lily Festival and the Shurijo Castle Festival.


Shurijo Castle

Cuisine from Okinawa is also famed for being delicious as well as healthy and the region has developed its own food culture which is rumoured in fact to contain the secret of longevity which Bob Heile thinks is no bad thing.
He says: "Although Japanese food is well known throughout the world the cooking of Okinawa is very different and I think it will be very interesting for our members and guests to experience it."
Ingredients such as sugar cane, brown sugar, seafood and pork all make it particularly appetizing and Okinawans have a saying 'nuchi gusui' which means that 'food is medicine'! Many dishes from Okinawa use 'ucchin' which contains an antioxidant effect called 'curcumin' – so perhaps eating like an Okinawan actually does give a long and healthy life!

And finally what does Mr. Bob Heile expect will be achieved this September? He says: "This is a meeting of standards groups – it's as simple as that – and often our membership comes early or leaves late to try and see something of the area we are in. We certainly plan to do that with Okinawa!"

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Japan Tourism Agency

775 Number of nuclear weapons that could have been made from radioactive material recently removed from a fast-breeder reactor in Kazakhstan.

update

SHARING SMARTS: A robot, part of the RoboEarth project, taps the cloud to learn how to serve a drink to a patient.
PHOTO: ROBOEARTH

Robots With Their Heads in the Clouds

A Google researcher argues that cloud computing could make robots smaller, cheaper, and smarter

IN ONE of the many famous scenes in *The Matrix* (1999), the character Trinity learns to fly a helicopter by having a "pilot program" downloaded to her brain.

For us humans, with our offline, nonupgradable meat brains, the possibility of acquiring new skills by connecting our heads to a computer network is still science fiction. Not so for robots.

Several research groups are exploring the idea of robots that rely on cloud-computing infrastructure to access vast amounts of processing power and data. This approach, which some are calling "cloud robotics," would allow robots to off-load compute-intensive tasks like image processing and voice recognition and even download new skills instantly, *Matrix*-style.

Imagine a robot that finds an object that it's never seen or used before—say, a box of cornflakes. The robot could simply send an image of the box to the cloud and receive the object's name, a 3-D model, nutritional information, and instructions on how to pour it.

For conventional robots, every task—moving a foot, grasping things, recognizing a face—requires a significant amount of processing and preprogrammed information. As a result, sophisticated systems such as humanoid robots need to carry powerful computers and large batteries to power them.

James Kuffner, a professor at Carnegie Mellon University, currently working at Google, described the possibilities of cloud robotics at the IEEE International Conference on Humanoid Robots, in Nashville, this past December. Embracing the cloud could make robots "lighter, cheaper, and smarter," he told the assembled engineers.

According to Kuffner, cloud-enabled robots could offload CPU-heavy tasks to remote servers, relying on smaller and less power-hungry onboard computers. Even more promising, the robots could turn to cloud-based services to improve such capabilities as recognizing people and objects, navigating environments, and operating tools.

The idea of connecting a robot to an external computer is not new. Back in the 1990s, University of Tokyo researchers explored the concept of a "remote brain," physically separating sensors and motors from high-level "reasoning" software. But the amount of computing power a cloud-connected robot has access to is far greater now than what the researchers imagined during the Web's early days.

Kuffner, who is a member of Google's autonomous car project, is now exploring a variety of cloud robotics ideas, including "using small mobile devices as Net-enabled brains for robots," he told *IEEE Spectrum*. Some of his colleagues recently unveiled Android-powered robot software and a small mobile robot dubbed the Cellbot. The software allows an Android phone to control robots based on platforms like Lego Mindstorms, iRobot Create, and Vex Pro.

But cloud robotics isn't limited to smartphone robots. It could apply to any kind of robot, large or small, humanoid or not. Eventually, some of these robots could become more standardized, and sharing applications would be easier. Then, Kuffner suggested, something even more interesting could emerge: an app store for robots.

The app paradigm is one of the crucial factors behind the success of smartphones.

CLOUD ROBOTICS PROJECTS

- **RoboEarth is** a European project led by the Eindhoven University of Technology, in the Netherlands, to develop a "World Wide Web for robots," a giant database where robots can share information about objects, environments, and tasks.
- **Researchers at** Singapore's ASORO (A-Star Social Robotics Laboratory) have built a cloud-computing infrastructure that allows robots to generate 3-D maps of their environments much faster than they could with their onboard computers.
- **Google engineers** developed Android-powered robot software that allows a smartphone to control robots based on platforms like Lego Mindstorms, iRobot Create, and Vex Pro.

- **Researchers at** the Laboratory of Analysis and Architecture of Systems, in Toulouse, France, are creating "user manual" repositories for everyday objects to help robots with manipulation tasks.
- **At a children's** hospital in Italy, Nao humanoid robots, created by the French firm Aldebaran Robotics, will rely on a cloud infrastructure to perform speech recognition, face detection, and other tasks that might help improve their interaction with patients.

TOP: CELLBOTS; BOTTOM: ALDEBARAN ROBOTICS

What could apps do for robotics? It's too early to say. But at the Nashville gathering, roboticists received Kuffner's idea with enthusiasm.

"The next generation of robots needs to understand not only the environment they are in but also what objects exist and how to operate them," says Kazuhito Yokoi, head of the Humanoid Research Group at Japan's National Institute of Advanced Industrial Science and Technology. "Cloud robotics could make that possible by expanding a robot's knowledge beyond its physical body."

"Coupling robotics and distributed computing could bring about big changes in robot autonomy," says Jean-Paul Laumond, director of research at France's Laboratory of Analysis and Architecture of Systems, in Toulouse. He's not surprised to see Google, which develops core cloud technologies and services, pushing the idea of cloud robotics.

But Laumond and others note that the cloud is not the solution to all of robotics' difficulties. In particular, controlling a robot's motion—which relies heavily on sensors and feedback—won't benefit much from the cloud. "Tasks that involve real-time execution require onboard processing," he says.

And there are other challenges. As any Net user knows, cloud-based applications can get slow or simply become unavailable. If a robot relies too much on the cloud, a hitch in the network could leave it "brainless."

Still, Kuffner is optimistic. He envisions a future when robots will feed data into a "knowledge database," where they'll share their interactions with the world and learn about new objects, places, and behaviors. Maybe they'll even be able to download a helicopter-pilot program. —ERICO GUIZZO

A version of this article appeared in IEEE Spectrum's *Automaton blog in January.*

BILLIONS OF BITS: This tiny chip of silicon produced a record 10 billion pairs of quantum entanglements.

PHOTO: JOHN MORTON/OXFORD UNIVERSITY

A Crowd of Quantum Entanglements

Phosphorus-in-silicon system could lead to quantum computers

In a flurry of research reports during the past six months, physicists have proven that silicon, the basis of computers today, could also be the best platform for tomorrow's quantum computers.

Such computers would use the quantum properties of atoms or molecules to perform calculations in a fraction of the time it would take conventional computers. However, so far only rudimentary quantum computers have been built, comprising only a few quantum bits (qubits) and built in exotic systems such as ion traps, cryogenically cooled superconductors, and optical tweezers.

Silicon could provide a useful path to systems with 100 or more qubits, say some scientists, because it would make quantum computers easily compatible with conventional ones. The silicon solution originated in 1998, when Bruce Kane, a physicist at the University of Maryland, in College Park, suggested making a qubit from the nuclear spin—a quantum property similar to magnetic moment—of the phosphorus atoms with which silicon is often doped.

In the past few months, researchers have reported progress in using the phosphorus-in-silicon system. In the latest development, a team of physicists led by John Morton of the University of Oxford reported that by using bursts of radio waves, they have managed to entangle the spins of 10 billion pairs of electrons and nuclei in a crystal of phosphorus-doped silicon. Entanglement is a phenomenon that allows quantum particles to be interlinked even if they are separated. It is used in quantum computing, along with another quantum phenomenon called superposition, to create qubits that can exist in many different states at the same time. The experiment is being hailed in the quantum computing community as a promising step toward silicon-based quantum computers.

According to Morton, the main advantages of his group's design are that it integrates easily with ordinary silicon circuits and that it produces qubits that last for a few seconds. In many other quantum systems, qubits last only milli- or microseconds, which makes it difficult to perform calculations.

Dane McCamey of the University of Sydney, whose research involves a similar system, says that what is important about Morton's work "is the generation of a large number of identical entangled pairs." McCamey and other experts, such as Stephen Lyon of Princeton, say these pairs could pave the way to a form of quantum computing where large entanglements are generated and then a series of precise measurements on individual qubits lead to massively parallel processing.

Though the Oxford experiment produced 10 billion sets of entangled pairs, the number that were usable as qubits was small, and that is unlikely to change soon.

Raymond Laflamme, executive director of the Institute for Quantum Computing at the University of Waterloo, in Ontario, Canada, cautions: "Some people are making the leap that we will have silicon quantum computers soon. We are on the right track, but the track is a long one." —*Saswato R. Das*

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the big picture

LOVE LIGHT IN FLIGHT

Visitors to Resorts World on the island of Sentosa, Singapore, can witness "The Crane Dance," a 10-minute animatronics spectacle in which two 80-metric-ton mechanical cranes act out a common fictional trope: the power of love infusing life into inanimate objects. The cranes appear to emerge from the water and flap their wings as they fall in love. The birds' 25-meter-wide wings are created with a spray of nearly 18 500 liters of seawater that shoots out of each bird's 10-story-high body during the course of every show.

PHOTO: WONG MAYE-E/AP PHOTO

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hands on

A TYPEWRITER IS A TERRIBLE THING TO WASTE

A manual typewriter's keyboard makes a perfectly good computer keyboard—with a little bit of hacking

IN THE 1940s, my mother tapped out her college term papers on what was then a snazzy new Royal typewriter. In the 1970s, she gave it to me for my high school essays. I, too, may pass a manual typewriter on to my kids, but with a twist—a couple of circuit boards bodged to the bottom and a USB cable coming out the back. An obsolete manual typewriter can thus be reborn as a computer keyboard.

It's the brainchild of Jack Zylkin, a Philadelphia-based electrical engineer who has designed a kit that makes the conversion reasonably easy for anyone who enjoys hands-on projects. Zylkin spent the better part of a year refining his creation at Hive76, a local workspace organized by hackers of various kinds. The typewriter modification is based on an Atmel ATmega168 microcontroller board, a pile of shift registers, and several dozen hand-hammered leaf-spring contacts.

Here's how the computer attached to the typewriter knows which key has been pressed: When a letter is typed, the key's metal support bar touches a single contact on the board. Meanwhile, the microcontroller is stepping a single logic "1" down the row of shift register pins and thus the leaf-spring contacts wired to them, letting the microcontroller detect the circuit made between the typewriter and the board. Then, like any other USB keyboard controller, it sends the appropriate code back to

OLD MEETS NEW: Three portable typewriters, a Royal [above], a Smith-Corona [below, right], and an Underwood [below, left], come out of retirement to serve as keyboards for, respectively, a Dell all-in-one computer, an iMac, and an iPad. *PHOTOS: JACK ZYLKIN*

the PC. A few strategically placed magnets and reed switches detect the shift key, carriage returns, and whatever the user wants to configure as Alt or Ctrl.

Why use shift registers instead of the switch matrix buried within a modern keyboard? Because ordinary humans can build it. A matrix would need fewer components and perhaps less code, but it would require either putting the microcontroller on the same board as the contacts (a tough fit inside some typewriters) or soldering more than a dozen wires between the two boards. The shift registers take only four wires. "The other advantage," Zylkin notes, "is that unlike some kind of matrix, the shift registers form a repeating pattern that can be cut to any length." So regardless of how large or small your manual typewriter, his board can be chopped to fit inside with no electrical repercussions.

Assembling the kit is fairly straightforward. There's a lot of soldering (40-odd contacts plus eleven 16-pin ICs), none of it particularly fussy.

The only unusual step is making the leaf-spring contacts yourself by flattening the leads of two dozen half-watt resistors with two hammers or a hammer and an anvil. Zylkin says that there are no easy sources for the kind of copper or phosphor-bronze strips that you can expect to use for making contacts. (As this article goes to press, Zylkin plans to phase the resistors out: "I'm taking your advice and moving away from resistor leads for the electrical contacts. From now on, the kits will use chemically etched brass strips for the contacts—no hammering required.")

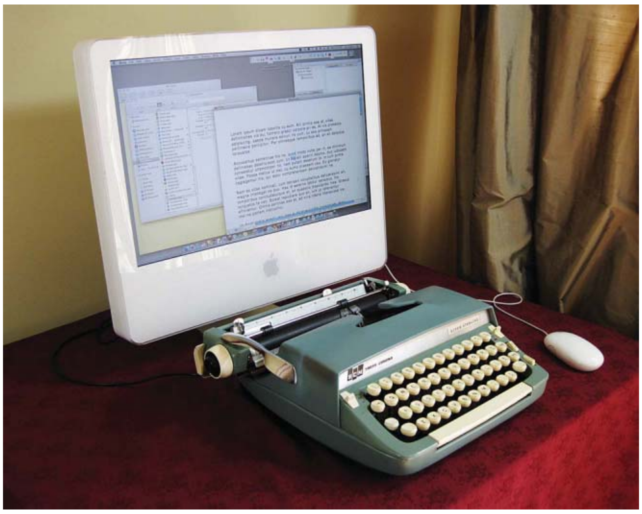
After a while, the rhythm of the work becomes almost automatic: Hold the resistor body while you pound a lead flat on the anvil, turn it over to flatten the other side of the lead, flip end-for-end to do the other lead, pick up another resistor, and so on.

Separately, you solder wires to some reed switches and wrap them in heat-shrink tubing to protect their fragile glass. Then, for example, you can mount a magnet on the carriage-return lever and one switch right next to it on the body of the typewriter, so that when you pull the lever the magnet closes the circuit and notifies the microcontroller that you've done the equivalent of pushing the return key.

Zylkin found that he needed to give special thought to designing a kit for do-it-yourselfers because some parts aren't easily found, while others would be hard to incorporate. It would have been nice, for example, to use off-the-shelf USB or Bluetooth ICs to handle the keyboard's communication with the rest of the world, but such chips are surface-mount only. Zylkin sells modified typewriters as well as kits and will modify typewriters sent to him. He recently left his corporate engineering job to build and sell retro-technology full-time.

So what is this retro-keyboard like to type on? For many of us, it'll be more comfortable than a modern-day one. Remember, manual typewriters were designed to be operated entirely on finger power for hours every day, and the key travel needed to reach contacts is only a fraction of the distance required in the old days to slam a type bar onto the platen. Now if only someone could go the other way around and build a CPU and some mass storage into the rest of the typewriter.

—Paul Wallich



profile

From QuickBooks to Slow Food

Ridgely Evers doesn't just write software for businesses, he keeps starting them up. Now he's making wine and olive oil

POUR HOUSE: Software entrepreneur and winemaker Ridgley Evers enjoys the fruits of his labors.

PHOTO: TEKLA S. PERRY

For Ridgely Evers, developing new technology has always been a means to an end. In boarding school, programming got him out of waiting tables. In college, he figured it would help bring world peace. In the 1980s, sick of keeping the books for a real estate start-up, he wrote software to do it for him.

"Manual bookkeeping is a stupid process," Evers says. "Spreadsheets are not a good place to do accounting, either."

In 1987, Scott Cook, the founder of Intuit, looked at Evers's accounting package and hired him as a consultant to write an invoicing add-on for Quicken personal finance software. Evers started working on the project but argued that small businesses needed a dedicated accounting package, not just an add-on. Cook finally agreed, and Evers set out to build what's now known as QuickBooks.

Evers led a design team of nine people, created the architecture, and wrote about 25 percent of the code himself. It came out in 1991, and today QuickBooks is still the world's most popular small-business accounting package.

While QuickBooks took the small-business accounting world by storm, Evers eventually left Intuit—then a 30-person outfit, now a public company with US $3 billion in annual sales—and built what he calls a balanced life. He does strategic consulting for large companies, and he is about to launch Captina, a company that will sell cloud-based software he created to handle inventory, marketing, order taking, and shipping for small businesses. Again, he was his software's first customer—he uses it to run his olive oil and wine company, DaVero.

Evers also manages his 28-hectare farm, where he grows the olives for his oil and grapes for his wine. Farming is one process, he's found, that technology can't do much for; plants have to grow themselves in their own good time. And he's just fine with that. "I really love and am proud of the diversity of my life," says Evers. "I never let myself get pigeonholed."

—Tekla S. Perry

For more about the origins of QuickBooks and how a technologist got into the olive oil business, see "From QuickBooks to Slow Food" at http://spectrum.ieee.org/evers0311.

careers

FOR DUMMIES FOR DUMMIES

You, too, can turn an interest in Carrier Ethernet or string theory into an idiot's guide

IT ALL BEGAN in 1991, when publisher IDG Books Worldwide irresolutely published Dan Gookin's *DOS for Dummies* in an initial press run of only 7500 copies. Two years and a million copies later, Alpha Books followed suit with *The Complete Idiot's Guide to DOS*.

Since then there have been 1600 For Dummies titles (now published by Wiley) and 1300 Complete Idiot's Guides, totaling 220 million copies. And authors and experts are still regularly being hired to pen the next installments in the franchises. Might you be next?

Be warned: It takes more than expertise, says technical writer Ed Tittel, whose *HTML for Dummies*, cowritten with Steve James and first published in 1995, is about to go into its 13th edition.

"The secret to writing a Dummies book is not in the knowledge," says Tittel. "The real test of a writer's mettle is being able to take complex contents and deliver them in everyday language in as friendly and nonthreatening a way as possible."

In addition to his six For Dummies trade books, Tittel has written five others for private companies—Wiley also leases out the For Dummies brand to companies looking to make an impression at trade shows or on sales calls. Tittel's roster of page-turners includes *Carrier Ethernet for Dummies* for the Maryland-based network firm Ciena Corp. and *Clusters for Dummies* for Canadian cloud software company Platform Computing Corp.

In fact, Tittel says, writing the custom booklets gives him a more "generous and relaxed schedule" than writing a retail For Dummies book. Custom titles run between 32 and 72 pages with deadlines of one to two months, whereas a first draft of a regular For Dummies book, which can be up to 400 pages, is often due in just four or five months. Custom titles have no royalties, but the payout tends to be more generous, Tittel says. Writing a trade edition involves both an advance up front, which varies depending on the writer's experience and the popularity of the subject, and royalties once the book has earned back its advance.

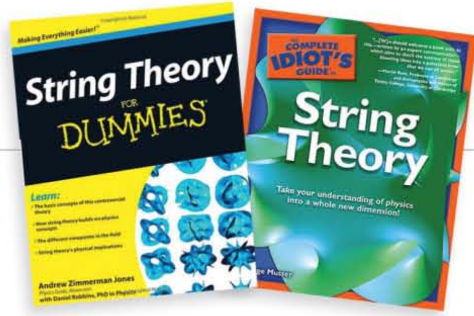
Be warned also that it isn't an easy niche to break into. Barbara Harvie, a Sebastopol, Calif.–based writer and entrepreneur who has carved out a niche writing user guides to Quicken, QuickBooks, and other financial software, says technical writing agent Carole Jelen McClendon contacted her about writing a Complete Idiot's Guide after reading Harvie's résumé on her LinkedIn page.

According to Bill Gladstone, founder of Waterside Productions, the literary agency for Harvie and for dozens of other For Dummies and Complete Idiot's Guides authors, 95 percent of the hundreds of titles they represent originated with the publisher. "It is rare that an unsolicited proposal results in a book contract," he says, "though it does happen occasionally."

And even if you get in over your head, you can bring in help from the outside. *String Theory for Dummies* author Andrew Zimmerman Jones—a science writer for About.com—says he penned the book's first draft on his own (see a review of *String Theory for Dummies* in this issue). On the advice of his editor, he sought out Ph.D. string theorist Daniel Robbins of Texas A&M University to help him sift through competing theories and advanced ideas.

"Daniel and I had several discussions to make sure that he was okay with the approach," Zimmerman Jones says. "And he agreed that in a reference book like this it was only fair to give the critics their due."

—MARK ANDERSON



books

STRING THEORY MADE EASY

Two books tackle one of the most complex theories known to man—with surprisingly satisfactory results

String Theory for Dummies
By Andrew Zimmerman Jones with Daniel Robbins; Wiley, 2009; 384 pp.; US $19.99; ISBN: 978-0-470-46724-4

The Complete Idiot's Guide to String Theory
By George Musser; Alpha/Penguin, 2008; 368 pp.; $18.95; ISBN: 978-1-59257-702-6

THERE'S A Complete Idiot's Guide or For Dummies book for just about everything, from caulking your bathtub to mastering JavaScript. How do they compare head to head? And how well do they handle the thorniest and most difficult topics in science today—say, string theory?

It's the big enchilada, the theory that unifies physics' greatest 20th-century achievements: relativity and quantum mechanics. String theory syncs these distinct views of the universe by hypothesizing seven additional dimensions of space plus a near-infinity of parallel universes that also can never be seen. Somewhere within this cauldron, infinitesimal loops of various vibrations wobble, giving us the "familiar" world of electrons, quarks, and neutrinos—as well as a menagerie of undiscovered particles that the theory predicts must exist.

Science journalists Andrew Zimmerman Jones (*String Theory for Dummies*) and George Musser (*The Complete Idiot's Guide to String Theory*) have taken on the herculean task of summarizing the universe, in all its photon/graviton/black hole/big bang glory. And that's just for starters. Each must then argue why we need string theory, explain its extraordinarily complex hypotheses, what it all means, and why readers should care.

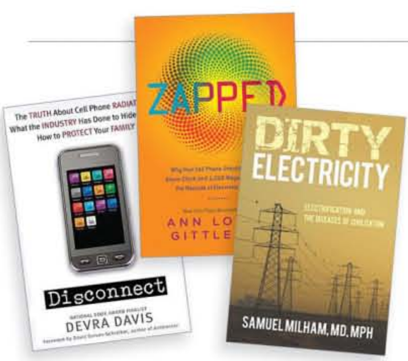
Zimmerman Jones makes an admirable effort. Struggling to explain a 25-dimensional (!) precursor theory, the author enlists a Slinky toy for a deft little metaphor. He then summarizes the case against string theory masterfully, candidly pointing out, for instance, that its acolytes never predicted "dark energy," one of the biggest physics discoveries since string theory's emergence in the 1980s. Nevertheless, if rankings must be made, award Zimmerman Jones the silver.

Musser is a joy to read. With an easy grasp not only of the central theory but its chief competitors—loop quantum gravity and other lesser-knowns—he condenses complex tenets like particle spin and statistical mechanics via clever comparisons to "The Newlywed Game" and salsa dancing. And his extended conceptualization of string theory as a corporate merger between two hostile companies is nothing short of brilliant.

Ironically, the best introductory tome would combine the two contenders, just as string theory itself does. Musser's breezy pages could use a little more of Zimmerman Jones's candor, such as the fact that there's no such thing as string theory but rather a vast number of theories.

In the end, the reader begins to feel for the seemingly impossible expectations heaped on string and related quantum gravity theories: Unify all known forces and particles while also making sense of the dawn of time, cosmic inflation, black holes, time machines, dark matter, and, while we're at it, dark energy, too. One gets a picture of Cinderella tasked with endless chores by wicked stepsisters hell-bent on breaking her. And more than anything else, it's clear she hasn't even met her fairy godmother yet.

—MARK ANDERSON



Murderous Microwaves

Three flawed books argue that the science of cellphone radiation hazards is flawed

Do you feel zapped, disconnected, or electronically polluted by electromagnetic fields in your home and workplace? Are you fearful of your electricity? These three books will offer ample justification—but, argues reviewer Kenneth R. Foster, nothing is new here. "The scientific literature on the health effects of electromagnetic fields is vast and inconsistent," he writes, "and has been for many years." Many journalists have written scary stories by picking and choosing data and speculating about motives of individuals, and these three writers have done that here, with their egregiously slanted reporting. At the same time, health agencies have repeatedly reviewed the data and failed to find a clear reason for concern.

Read the review online at http://spectrum.ieee.org/cellbooks0311.

Disconnect: The Truth About Cell Phone Radiation, What the Industry Has Done to Hide It, and How to Protect Your Family
By Devra Davis; Dutton, 2010; 271 pp.; US $26.95; ISBN: 978-0-525-95194-0

Zapped: Why Your Cell Phone Shouldn't Be Your Alarm Clock and 1268 Ways to Outsmart the Hazards of Electronic Pollution
By Ann Louise Gittleman; HarperOne, 2010; 272 pp.; $25.99; ISBN: 978-0-06-186427-8

Dirty Electricity: Electrification and the Diseases of Civilization
By Samuel Milham; iUniverse, 2010; 120 pp.; $12.95; ISBN: 978-1-4502-3822-9

geek life

KEITH BROFSKY/GETTY IMAGES

LOVE, DIGITAL STYLE

Everything else gets a feedback rating, so why not last night's date?

"I WENT ON a date and I thought it went pretty well. But then after a few days, my date wasn't taking my phone calls. I started to wonder, 'Was it my hair—or lack of it? Maybe I just talked too much?' Or maybe she just didn't feel a spark. The point is, I didn't know…I wish I had DateRate!"

So began Web developer Gabe Hallombe's pitch for DateRate.com.au during the Australian start-up competition Sydney Startup Camp IV last October. The program, which won an honorable mention, lets you request anonymous criticism on such areas as grooming, sense of humor, and conversation from dates you've had through the site. "Sometimes the things we need to hear the most are the hardest things for people to say," says Hallombe. "DateRate makes sharing feedback easy." It's the latest in a growing and addictive niche of feedback and information sites dedicated to dating.

Florida-based computer programmer Kim Moser began DateRate—an unrelated U.S.-based site—in early 2004 as a goof, after using "traditional" dating sites Match.com and eHarmony. "I was curious to know what people thought of me," says Moser, who estimates that his site logs a few thousand visitors a month by word of mouth. That need for feedback is the basis of other sites as well, such as Hot or Not, which rates people on how they look on a scale of 1 to 10. "It's hugely popular with a very base appeal to it," Moser says. "It's like potato chips. You cannot stop doing this."

Moser surmises that the popularity of sites like his has picked up as a reaction to other sites, such as DontDateHimGirl.com, where women share information about dating, relationships, finances, and self-esteem.

Because Moser's users also list the dating site they got their date from, he says he was able to compile a rating system for the dating sites themselves, such as which had the most accurate pictures or produced the most successful dates. And at least one site gives out a lot of information about itself: OKCupid has a blog that analyzes dating trends based on information gleaned from its users.

Technology is making other appearances in online dating as well. Skout and HG Apps Store's Date Radar can connect you with nearby singles via GPS technology. Cheek'd and FlipMe use cheeky business cards with a code. If you meet someone in person who appeals to you, hand him or her the card, which has a link to the dating site. The idea is that it's safer to learn about someone online than in person.

That might be true. Consider WomanSavers.com, which serves as an early warning system for women before they date. Stephany Alexander started the site in 2002 after a bad relationship. "I thought, 'There should be a network for women to share information,' " she says. Through Alexander's site, a group of older women in seven states found out they were married to or involved with the same man, while a single mother learned her boyfriend was a pedophile. Alexander says, "Ninety percent of the men entered do not have positive reviews—alleged pedophiles, men spreading STDs, abusive men, and serial bigamists." Despite hackers and legal threats and being banned in China, parts of Russia, and the Middle East, the site has grown to include more than 40 000 men's names.

While the U.S. company DateRate is not a moneymaker, DateRate.com.au sees financial potential in selling targeted advertising, charging users to access their feedback and customize their questionnaires, and licensing its software to traditional dating sites. DontDateHimGirl.com and WomenSavers.com, which run ads, engage in e-commerce, or charge some fees, have helped brand their creators as relationship experts. —SUSAN KARLIN

DateRate.com.au: *http://daterate.com.au*
DateRate: *http://www.daterate.net*
Hot or Not: *http://www.hotornot.com*
DontDateHimGirl.com: *http://dontdatehimgirl.com/home*
OKCupid's blog: *http://blog.okcupid.com*
Skout: *http://www.skout.com*
Date Radar: *http://hgappsstore.com/dp616/ourappportfolio/date-radar*
Cheek'd: *http://www.cheekd.com*
FlipMe: *http://flipmedating.com*
WomanSavers.com: *http://womansavers.com*

reflections

BY ROBERT W. LUCKY

Open Systems

CHRISTIAN NORTHEAST

OCCASIONALLY, I indulge in a bit of nostalgia over those long-ago days of Heathkit. Of course, building a Heathkit was the electronics equivalent of painting a Rembrandt by the numbers, but I remember how proud I was when a project was done. It was a great starting point for growing up to be an engineer. There's something else to cherish about those Heathkits, though: their openness. Whatever might go wrong with the Heathkit, I could fix it. I had access to all the parts and complete schematics and circuit descriptions. It was truly mine.

The electronics world of today is profoundly different. None of the many gadgets that litter my house could be considered open. "No user-serviceable parts inside" is the ubiquitous phrase of warning—you're apparently going to be electrocuted if you open the back of the gadget, and worse yet, you'll void the warranty. Many won't let you add memory or even change the battery!

These systems couldn't be more different from the old Heathkits. For one thing, they seldom break, so information about how to fix them is unneeded. There's almost nothing inside anyway, just an embedded processor and some firmware. And whatever this gadget is and does, with a change in firmware it could be and do something different—except, of course, that you're not allowed to touch it. In contrast, the old Heathkit—which you were allowed, even encouraged, to touch—was what it was, and could never be different.

Manufacturers are understandably reluctant to open their designs. They fear someone will reverse engineer the product, produce it more cheaply, and undercut their market. They also worry about supporting users who've crippled or ruined their devices.

Some consumer devices get opened up by hackers—a trick known as jailbreaking—and, while strictly speaking, this might be illegal, a bit of anarchy might not be entirely bad if it stimulated innovation. Indeed, there are a number of examples of open systems built on top of others, some of which are closed. In recent decades we have seen the tremendous value in opening innovation up to the public by providing a stable platform. The Internet itself is the greatest example—a core platform consisting of a set of protocols on which millions upon millions of people have innovated and created enormous value for all humanity.

On a smaller scale we have partially open systems that have inspired a great deal of innovation. Many have application programming interfaces that allow third-party add-ons. More recently, the advent of the app store has provided a wonderful model for allowing public innovation around a closed, proprietary platform. For the platform manufacturer, this can increase its market many times, and at little expense.

In maintaining a stable platform there is always the danger of being painted into a corner, where it becomes impossible to change the platform because of everything that has come to surround it. Microsoft Windows is a prime example, as is the Internet itself. A lot of people, now given the benefit of hindsight, would like to change the underlying protocols of the Internet. But the weight of legacy is so overwhelming that even the thought of such change is heresy.

The whole question of how much and where a system should be open is fascinating. With the PC, IBM opened the design to third parties, while Apple maintained a closed design. The market chose the IBM design, but it was ultimately a market in which IBM itself had no inherent advantage. On the other hand, Apple has been able to maintain its market—albeit with a much smaller share—through the years, as well as its independence and design integrity. It retained the freedom to break a lot of legacy software when it created a completely new operating system, Mac OS X, an option that Microsoft doesn't seem to have.

As an engineer, I'm conflicted. I don't like these devices that lock me out. But intellectually, I understand that manufacturers have to make money or they wouldn't be able to create these great products. I also understand the value of maintaining stable platforms. Nevertheless, I'm an engineer and yearn to tinker with these closed boxes. It's what I grew up doing. ❑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merica online
aol instant messenger
twitter.com
myspace.com

by ARIEL BLEICHER

A MEMORY of WEBS PAST

EVERY WEEKDAY AT 5:00 A.M., A NONDESCRIPT GRAY VAN rolls down the underground service road beneath the French National Library, in Paris, and arrives at a svelte glass skyscraper soaring above the bustling Seine River. Here, at the Tower of the Times, the van delivers a tiny but astoundingly rich snapshot of life in this country that takes its cultural heritage very seriously.

The Web is a rollicking, revealing record of life in the 21st century. But preserving it for future historians is a monumental technical challenge

The van has been stuffed willy-nilly with two copies each of some 3000 periodicals printed recently in France that are being sent to the library for preservation. One morning last November, the haul includes the dailies *Le Monde* and *L'Humanité*, of course, and also the union newspaper *Le Travailleur*. Among the other lexical artifacts dutifully funneled from the van up into the tower are a booklet of classified advertisements, a concert flyer, several religious pamphlets, *Busty Beauties* magazine, and a community newsletter from Bonnes (population 330) announcing a town raffle for three hams, six bottles of wine, and a yogurt-making machine.

"We have a lot of so-called crap, and we're happy about that," says Gildas Illien, an archivist at the library. His colleagues in other countries might turn up their noses at hard-core porn, advertisements, and obscure newsletters, but not Illien. "In a hundred years, what's totally irrelevant or dirty today will end up becoming of extreme interest to historians," he declares.

JUDE BUFFUM

THE TOWER OF THE TIMES, where Illien works, is one of four spires, each composed of two perpendicular wings resembling the pages of an open book, that make up France's newly modernized national library. The archivists here aren't after just printed material; they're preserving the electronic, too. In fact, it's Illien's daunting task to archive French Web sites—all of them, in all their evanescent, constantly changing, and multimedia splendor.

Since the ancient Sumerians compiled the first collections of inscribed clay tablets, many peoples have attempted to preserve documents, ephemera, and even the flotsam of their political, economic, and social tides. But perhaps no nation today tackles this endeavor as thoroughly as France, one of the few countries in which archivists have the legal right to copy and save virtual documents without fear of a copyright suit. Five centuries ago, King Francis I ordered book publishers to donate copies of their work to posterity. That legal deposit law, as it is known, has expanded over the years to include maps, music scores, periodicals, photographs, sound recordings, posters, motion pictures, television broadcasts, computer software, and finally, in 2006, the World Wide Web.

French archivists are still grappling with that most recent mandate. The Web, of course, is unlike any other publishing platform—not simply because it is amorphous and immeasurably large but because its "documents" are boundless. Nowadays, an "online publication" is barely recognizable as a publication in any traditional sense; it exists in a perpetual state of being updated, and it cannot be considered complete in the absence of everything else it's hyperlinked to. Unlike books and newspapers, which have discernible titles, authors, beginnings, and ends, the Internet is utterly nonstandardized.

The task of preserving what's put online has proved, to no one's surprise, monumental. And it's only getting more so as the Internet expands, as Web sites become more dynamic, and as concern grows over online privacy. Increasingly, much of what people put online is being diffused across social networks and distributed through personalized apps on smartphones and tablet computers. The classic Web site, it seems, is already starting to slide toward obsolescence. "I'm convinced the Web as we know it will be gone in a few years' time," Illien says. "What we're doing in this library is trying to capture a trace of it." But to do even that is requiring engineers to build a new, more sophisticated generation of software robots, known as crawlers, to trawl the Web's vast and varied content.

ILLIEN SEES HIMSELF AS A STEWARD of an ancient tradition; he believes he is helping pioneer a revolution in the way society documents what it does and how it thinks. He points out that since the end of the 19th century, the French National Library has been storing sales catalogs from big department stores, including the famous Galeries Lafayette. "Today," he says, "this exceptional collection...is the best record we have of how people dressed back then and who was buying what." One day, he insists, the archives of eBay will be just as valuable. Capturing them, however, is a task that's very different from anything archivists have ever done.

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A CULTURAL REPOSITORY: Every day, thousands of books, periodicals, brochures, and street flyers pass through the sorting rooms [above] in the basement of France's national library [left]. Eight stories above, a team of Web archivists hunt down digital documents and archive them in PetaBox storage servers [top] designed by San Francisco's Internet Archive.
PHOTOS: BIBLIOTHÈQUE NATIONALE DE FRANCE

The Web is regularly accessed and modified by as many as 2 billion people, in every country on Earth. It's a wild bazaar of scripting languages, file formats, media players, search interfaces, hidden databases, pay walls, pop-up advertisements, untraceable comments, public broadcasts, private conversations, and applications that can be navigated in an infinite number of ways. Finding and capturing even a substantial portion of it all would require development teams and computing resources as large as, or probably larger than, Google's.

But Google, aside from saving previously indexed pages for caching, has mostly abandoned the Webs of the past—the complete set of Web pages as they existed a month, six months, a year ago, and so on, back to a site's origins. Thus the job of preserving them has fallen to nonprofit foundations and small, overworked teams of engineers and curators at national libraries. Illien, for example, manages a group of nine.

For a digital archive, the French National Library's collection of Web data is surprisingly small—just 200 terabytes stored on hard disks and magnetic tape in the library's data center. It includes copies of French Web pages dating back to 1996. Illien's team completed its first harvest of the entire French domain (.fr) just last summer. Other national libraries, such as Iceland's, have been downloading their national domains periodically since the early 2000s.

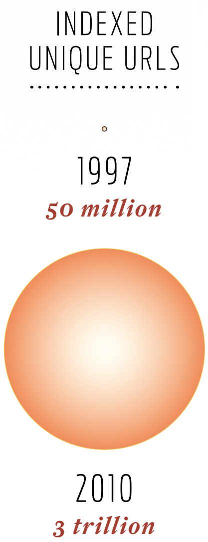
Part of the difficulty in fetching the contents of the Web is that no one really knows how much is out there to be fetched. Brewster Kahle, a U.S. computer engineer who in the late 1980s invented the Wide Area Information Servers, a pre-Web publishing system, paid a visit to AltaVista's offices in Palo Alto, Calif., in 1995. He was shocked to see that the then-popular search engine had indexed 16 million Web pages "on a set of machines that were the size of two large Coke machines," he recalls. "You could actually wrap your arms around the Web."

The apparent compactness of the Web inspired Kahle to found, in San Francisco in 1996, the nonprofit Internet Archive. Wary of infringing on copyrights, AltaVista made sure to delete old pages in its cache. But the Internet Archive, emboldened by its status as a trustworthy nonprofit, was willing to be brazen. "We have an opportunity to one-up the Greeks," Kahle says, referring to the ancient philosophers who collected hundreds of thousands of papyrus scrolls in the great Library of Alexandria. The invention of the Internet, he argues, has made it possible to create an archive of human knowledge that anyone can access from anywhere on the planet. And Kahle, for one, wasn't going to let a bunch of lawyers talk him out of it.

By March 1997, he had compiled what was arguably the first true time capsule of the global Web. In fact, a substantial portion of the French National Library's electronic archive was simply bought from Kahle's Internet Archive. One of the archive's major successes has been its online access interface, called the Wayback Machine, which lets anyone who knows the address of a Web site see archived versions of its pages. Today the Internet Archive stores more than two petabytes of Web data in a portable Sun Microsystems (now Oracle America) data center built into a shipping container. Back in 1997, Kahle had captured nearly 2 terabytes, which he calculated was about a tenth the amount of text stored in the entire U.S. Library of Congress. It was a substantial collection of the Web of the time, but it wasn't nearly everything.

Kahle knew there were still hundreds of thousands of sites and perhaps millions of "hidden" documents, images, and audio clips that his crawler program missed. It couldn't access password-protected sites, for example, or isolated pages with just a few if any hyperlinks, such as outdated product postings on eBay. More troubling, it couldn't probe "form-fronted" databases, which require typing keywords in search boxes to call up information (such databases include those at the National Climate Data Center in the United States and the British Census). Still, Kahle believed that with the right tools and enough human curators to guide the crawlers, it was possible to get almost all online data. The Web may have been big, but ultimately it was manageable.

That is no longer the case. The part of the Web indexed by search engines such as Google has ballooned from some 50 million unique URLs in 1997 to about 3 trillion today, according to the latest update last November by Majestic SEO, a search optimization service. A URL, or uniform resource locator, designates a single document, such as a JPEG image or an HTML text file. Those files, however, are just a tiny piece of the Internet. By some estimates, the total "surface" Web visible to crawlers is six times the size of the indexed Web, and the "deep" Web of hidden pages and databases is some 500 times larger still.



COUNTING URLS, THOUGH, has become a fairly pointless exercise. For instance, it's possible and increasingly common that a single site is capable of generating vast numbers of unique URLs, all pointing to the same content: advertisements or pornography, typically. Though engineers have devised tricks for steering crawlers away from such spam clusters, even Google's crawlers still from time to time capture billions of unique URLs redirecting to the same place.

"In reality, the Web is infinite in all the wrong ways," laments Julien Masanès, who introduced Web archiving at the French National Library in 2002 and managed the collection until 2004, when he left to start what is now the nonprofit Internet Memory Foundation, headquartered in Amsterdam and Paris.

Realizing the Web's anarchic nature, its early archivists quickly gave up trying to dig up documents from every nook and cranny and instead focused on making quality copies of the pages they knew they could find. After all, they were building historical archives, not indexes of live sites, and it was imperative that their crawlers retrieve complete and perfect replicas. The trick was having a program that could fetch everything—not just text, which was what most search crawlers prioritized, but also images, graphics, and video.

When Kahle first started saving copies of Web documents in the late 1990s, he was trawling the Web with a crawler he helped develop for Alexa Internet, a search company he founded in 1996, the same year he established the Internet Archive. But three years later, he sold Alexa to Amazon.com, along with the rights to its software. No big loss, he figured. Alexa would still donate its twice-yearly global Web crawls to the Internet Archive, and in the meantime, Kahle and his engineers would build a crawler that was open source, meaning that anyone wanting to use or modify the software could download it for free. "Companies come and go," Kahle says, and because the goal is to build an archive of the Web that would last indefinitely, "the idea of depending on corporately controlled software is not a long-term strategy."

So Kahle hired a young Internet software developer and self-described "steward of open source" named Gordon Mohr to take charge of coding the crawler that would ensure the world's digital inheritance. Mohr had few good models to work from. "In the earliest days of search crawlers, an awful lot of them immediately reduced a site to plain text," Mohr notes, explaining that the "index quality" crawlers weren't made to preserve a site's "original appearance and functionality." But in January 2004, he released the first public version of his "archival quality" crawler and named it Heritrix, an archaic synonym for "heiress."

BEFORE HERITRIX, FEW LIBRARIES in the consortium had developed the technology to do any real archiving of their own. The problem was mainly a lack of resources. "We're too small, we're not smart enough, and we're terribly French," Illien explains, only half joking. Most libraries, including the French

JUDE BUFFUM

How to ARCHIVE the WEB

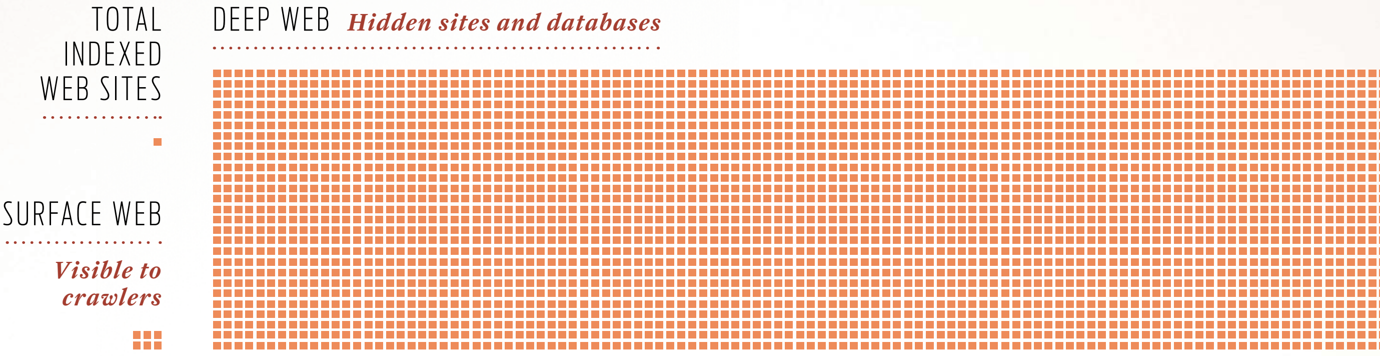
1 HERITRIX is a Web app that crawls the Internet for sites to archive.

2 A Web archivist creates a "CRAWL JOB" to outline each search's parameters.

3 THE CRAWL JOB also includes a starting list of URLs to analyze. This information is fed to a management layer in an app called the Frontier.

4 THE FRONTIER keeps track of all the URLs that Heritrix will discover and archive. It supplies new URLs to hundreds of multithreaded fetch requests called toe threads. The Frontier also makes sure that URLs are not revisited unnecessarily.

5 TOE THREADS are assignments to fetch and archive URLs. Hundreds of these operations occur simultaneously. Each thread starts by requesting a new URL from the Frontier. The URL is fetched, analyzed, archived, and then reported back to the Frontier.



National Library, have eagerly adopted Heritrix. But Heritrix is far from a turnkey solution. Configuring it and guiding it through cyberspace require nontrivial engineering mastery and on-the-job innovation. It's not at all like transferring your iTunes library from one computer to another.

"It's more like playing, eh, you know the game *Tetris*?" says Annick Lorthios, who works with Illien at the French National Library. Part of her responsibilities is monitoring Heritrix as it harvests things from cyberspace, which in order to crawl through all things French (stuff on the .fr domain, mostly) takes about two months. It sounds fun, except in this game, if you lose, either your system crashes or you end up storing a lot of junk you don't want, like 5 billion copies of a credit card ad.

Getting Heritrix to fetch the things you do want, explains Sara Aubry, who leads the two programmers on Illien's crew, is about making rules—"setting parameters," she calls it. For example, she can order the crawler to "Stay inside this domain" or "Don't even think of downloading more than 80 terabytes of data" or "For heaven's sake, stay away from URLs that look like *those!*" Then she gives the robot a list of places to go—about 1.6 million URLs purchased from the French domain registries, for example—and sends it on its way.

Heritrix enters cyberspace through this seed list of URLs, which, like street addresses, tell the robot where documents reside. In an ideal world, the crawling process happens like this: Heritrix follows each URL to the server that's storing the document and asks the server, "Do you have this document?" The server responds, in effect, "Yes. Here it is." Heritrix downloads the document, then scans it for more URLs. If those URLs lead to real things and Heritrix hasn't seen them before, they go in a "things to be downloaded" queue—one for each server the robot visits.

As Heritrix downloads the documents in its queues, it parses them for still more URLs, zipping from server to server, diffusing across the Web. Simultaneously, the crawler adds a few notes about where it found the documents and when, then stuffs them in big "suitcase" files, which are themselves piled up, compressed, and stored on disks.

Rarely, though, do things go so smoothly. The Web is a nasty place for a crawler, full of "crawler traps." A Web site with a calendar, for example, can unintentionally stall a crawler and keep it from fetching useful things. If each page of the calendar generates a link to the next day or the next month, it will create new URLs for every date until eternity, and "stupid Heritrix," as the Internet Memory Foundation's Masanès says, will ask for them all, one by one.

Sites that intentionally spam, known as spam clusters, are much more sophisticated. They involve heavily cross-linked networks of content that's often stolen or copied from other sites. The pages of a spam cluster all cross-reference one another, creating the illusion that a lot of people are linking to a site. The upshot for the spammer is that if Google's crawlers fall into this trap and index the site, its page rank improves dramatically, which makes Web surfers more likely to find it and click on it.

Such crawler traps are an archivist's nightmare. Let your crawler fall into a few and your archive is quickly spammed with billions of worthless files. Let your crawler fall into too many and the computing power needed to deal with such a large pool of URLs can overwhelm your servers and crash your system. The traps are why Illien's coworker Lorthios thinks of monitoring Heritrix as like playing a round of *Tetris*: Let too many blocks of the wrong shape stack up and your screen fills before you can win any rows. Game over.

For big crawls, it's easy to miss noticing that your crawler is gathering spam; the software downloads so many URLs so quickly that you may simply overlook a chain of suspiciously similar URLs in one of thousands of queues. Web archiving engineers can code special spam filters for Heritrix. Yet spammers are always inventing new tricks, and no mathematical method can warn Heritrix about them all.

The variability of Web formats has become a big problem for Heritrix, not just for avoiding traps but for capturing content. When Mohr designed the crawler's original architecture in 2003, the Web consisted mostly of pages of HTML text. "A Web page was just a file and everything was in the file," says Jérôme Thièvre, a software engineer at the French National Audiovisual Institute, in Paris, which archives French television and radio, including Web broadcasts.

Heritrix had no problem finding documents in a file; that was what it was built to do. But as the Web evolved, it grew into "a kind of jungle in terms of technology," Thièvre says, and archivists are particularly worried about being able to capture its newest design fad: rich media.

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Rich media is pretty much anything that moves when you interact with it. It can be a Flash animation, or a streaming video clip, or an image rotator that changes when you mouse over it. The pages describing this kind of media are coded in such a way that your actions within a browser—clicking a Play icon on a video player, for example, or typing an address into Google Maps—generate or trigger visible content. But Heritrix, because it looks for ordinary HTML files, fails to recognize the more dynamic components of these pages. So when Heritrix crawls sites heavy in rich media, it can miss as much as 40 percent of their content.

A few developers, particularly those at the Internet Archive and the Internet Memory Foundation, are experimenting with ways to get around this problem and patch the holes in their archives. They are building supplemental crawlers that act more like browsers, for example, or configuring Heritrix to work collaboratively with other downloading programs, and they have had some success. But most archivists lack the servers and funds to develop new tools and are simply doing the best they can with the ones they have.

"Right now, we're 100 percent ready to archive the way the Web was 10 years ago," Aubry says. "You know, plain HTML pages, nothing's moving around, not a lot of video—just images and text."

EARLY ARCHIVISTS NEVER ANTICIPATED that their biggest obstacle to building a comprehensive archive of the most accessible knowledge base in history would be providing access.

In most countries, including the United States, legal deposit laws don't apply to the Web. Copyrights, on the other hand, do. So in the strictest interpretation of copyright law, it's illegal for anyone, even a national library, to make and share copies of an electronic document, whether it's a music file or an online news brief. "Plenty of newspapers are earning money from charging readers to access their archives," explains a lawyer for the Library of Congress. "They could lose that money if we provide the content."

"That said," interjects Abigail Grotke, who leads the library's Web-archiving team, "it really crimps our Web-archiving style." In respect of U.S. copyright law, Grotke's team archives only government Web sites and several thousand select sites whose publishers have sent written consent.

The risk of inviting copyright lawsuits has driven other institutions to create "dark archives"—copies of their complete national domain that no one can see—with the hope that eventually the law will change. "I worked for six years putting things in the box without giving access to all that data," says Aubry, who was hired at the French National Library in 2002. "We used to call it the 'black box.' The first day we opened our collection [in 2008] was a happy day."

Still, the French National Library's Web archive isn't accessible to everyone. In fact, the archive is open only to researchers and browsable only through the computers in the library's reading rooms. Illien worries that if he tries to make the archive publicly accessible through the Web, France's personal data protection agency (Commission Nationale de l'Informatique et des Libertés), which hasn't yet legislated on Web archives, will step in and limit access even further—something that's already happened in Denmark and Norway. The agency strives to help French citizens retain control over their own information—to protect the teenager, say, who naively published pictures of herself on her Web site and doesn't want future employers to see them.

Most Web archives are similarly restricted, which frustrates idealists like Kahle. The Wayback Machine has existed online without controversy since 2000, he points out. And although the Internet Archive will remove a site from the Machine at the owner's request, few people have asked. "If we don't want to lose what it is we've built as humans—this enormous effort of putting knowledge on the Internet—we've got to go and not only capture it but make it accessible again," he insists. When he helped establish the International Internet Preservation Consortium eight years ago, he had hoped the national libraries would lead the charge. "Frankly, they've failed," he says. Indeed, while the Wayback Machine receives an estimated 400 000 unique visits a day, the Web archive at the French National Library gets just 80 users a month.

Though Illien would like to see his archive go online someday, he doesn't see the point in rushing things. "Users will come when the Web is dead," he declares as he waves me through a security desk and into the library's reading room. It is dimly lit, with a lofty, arching ceiling, and creepily quiet.

Crouching over a computer terminal, he shows me an early selection from one of his favorite collections, which consists of prototypical French weblogs. Illien loves how this archive distills the essence of the Web's larger evolution. "Early on, only computer geeks could write a blog," he whispers, grinning at the screen. "So the first stories of the Web were stories of the ordinary life of nerds. Then Web sites became more accessible, and you get love stories, travel diaries, people writing about their lives from the wildest parts of society."

He selects the blog, from 1997, of a computer science student. It's titled "MöngôlO's Diary (Almost)." The first entry begins *"Une de mes grandes phobies est de ne pas être compris"*: "One of my greatest fears is not to be understood." You can almost picture MöngôlO, hunched like Illien over a boxy gray monitor, trusting that the Web would free him from oblivion and misunderstanding. By 2001, his blog had vanished off-line.

But it's not gone for good. It still exists (almost), stored safely as electronic bits inside a whirring machine room in a library in Paris. ❑

JOIN THE DISCUSSION at http://spectrum.ieee.org/webarchive0311.

THE HUNT FOR THE BIOLOGICAL TRANSISTOR

HOW GENETIC CIRCUITS WILL UNLOCK THE TRUE POTENTIAL OF BIOENGINEERING *BY* JULIUS B. LUCKS & ADAM P. ARKIN

In 1977, a small group of researchers in California changed the world when they wrangled a common gut bacterium into producing a human protein. Using every technique in the book—and inventing some of their own—they scavenged, snipped, and glued together genetic components to synthesize a tiny filament of DNA. They then inserted the new segment into some *Escherichia coli* cells, tricking them into making the human hormone somatostatin.

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PHOTO: DAN SAELINGER; STYLIST: LAURIE RAAB/HALLEY RESOURCES; MAKEUP AND HAIR: GREG CLARK/ HALLEY RESOURCES

A year later, these scientists had an *E. coli* strain that produced insulin, an invaluable drug in the treatment of diabetes. With that, the era of biotechnology was born. A plethora of novel—or at least cheaper—drugs seemed to loom on the horizon.

Thirty-odd years on, molecular biologists have delivered on many parts of that early promise, engineering microbes to produce a wide range of pharmaceuticals, including experimental antimalarial medicines and antibiotics. A quick glance in the pantry or storage closet is likely to reveal other products of genetic engineering, too, including foods, food additives and colorings, and even laundry detergent. The list goes on and on.

The economic impact of all this has been enormous. Genetic engineering and other forms of biotechnology account for some 40 percent of the recent growth in the U.S. gross domestic product, for example. The biotech sectors in other countries have also made sizable contributions to their economies. And you can expect that trend to continue as genetically engineered organisms tackle even more diverse challenges, such as producing renewable fuels and cleaning up toxic waste.

Genetic engineers have indeed accomplished a great deal, but they've also run up against many obstacles in transforming microbial cells into factories that churn out useful substances. In a real-world factory, you need all your production machinery and employees operating in sync to run an efficient business. A cell also has components that act like machines, producing complex biological molecules, and other parts that act like messengers, ferrying around information in the form of chemical signals. Bioengineers have to do quite a bit of tricky fine-tuning to their cellular factories, manipulating the operation of many subcellular components so the cells don't die as they crank out the desired product in copious amounts.

For the bioengineers who do that tuning, a more apt analogy than the factory is that of an electronic circuit. We essentially want to make a cell programmable. We'd like to give it a command and have it perform a new function, just as if it were a tiny computer. To gain this power, we first need to amass a collection of well-characterized biological circuit elements that we can arrange however we like. This is one core focus of a subset of bioengineers, known as synthetic biologists, who are trying to revamp how genetic engineering is done.

Synthetic biologists take their circuit analogy quite seriously, despite the fact that a cell is a whole lot squishier than a silicon wafer or circuit board. A cell is basically a little bag full of biomolecular signals that cause cellular machinery to read chunks of DNA and with that information produce other useful biomolecules, typically proteins. Millions of different kinds of proteins are found in nature, and they participate in countless cellular processes, including the very ones that govern their production.

In a cell, certain proteins can influence pieces of DNA that code for something else. Those gene products can in turn affect other stretches of DNA and so on, forming complex webs of biochemical interaction. Think of these as the genetic circuits making up the cell's CPU. If you want to program a cell to do something specific, you need a way to build—or at least control—these genetic circuits.

Developing the requisite cellular control mechanisms is one of this century's great technical challenges. The two of us belong to two of the largest academic groups pursuing this goal: the Synthetic Biology Engineering Research Center, based at the University of California, Berkeley, and the BIOFAB: International Open Facility Advancing Biotechnology, which has its headquarters in nearby Emeryville, Calif. The goal of both projects is to help genetic engineers configure organisms the same way electrical engineers configure complex circuits. You could say we're trying to put some honest-to-goodness engineering into the 30-year-old discipline of genetic engineering.

Elaborate Lego creations, skyscrapers, and integrated circuits all have one fundamental feature in common: They are built from a multitude of simple constituent parts, which interact with one another in predictable ways.

Take electronics. Cellphones, iPads, and similar gadgets contain many millions of individual components, some highly specialized, some more generic. The latter category includes their many resistors, capacitors, and transistors. To reduce them to their bare essence, these generic parts take an input signal, transform it, and spit out a result. The same elements are used over and over for all sorts of things, their function being a product of their particular arrangement.

Curiously enough, the genetic machinery inside a cell works in much the same manner. It takes certain input signals—the concentration of one or more kinds of molecules—processes them in some fashion, and produces an output signal, the concentration of yet another kind of molecule. The problem for genetic engineers is to create the right processing "circuitry" to get a particular job done. This is tougher than in electrical engineering because the necessary parts have generally had to be handcrafted and assembled from scratch each time by teams of Ph.D.s working at the cutting edge of molecular biology. Someone trying to engineer a cell to do something new can't just mix and match standard components from a library of well-characterized parts the way electrical engineers generally can.

We and other synthetic biologists hope to change that. If we are successful, genetic engineers will one day be able to draw on a set of industry-standard tools for design and simulation. They will then combine widely available and well-characterized components to fashion organisms that produce valuable molecules.

So just how would you do that? To start with, you need hardy and prolific cells, typically bacteria or yeast, to serve as biological factories. These cells are easy enough to come by. But in most cases, you won't get them to crank out the molecule you want without first manipulating the machinery inside them. It's their genes that determine the nature of the molecules they make, so their genes are what you need to alter.

As you may recall from high school biology class, a gene is a segment of DNA containing a set of instructions for producing something (typically a protein) along with other bits and pieces that help control when that particular something gets made. When biologists talk about expressing a gene, they're referring to the many things that have to happen for those genetic instructions to be carried out. Cells use sophisticated means to control their genes, turning individual ones on and off as needed. They have to be sophisticated, because the process of switching a gene on is complicated.

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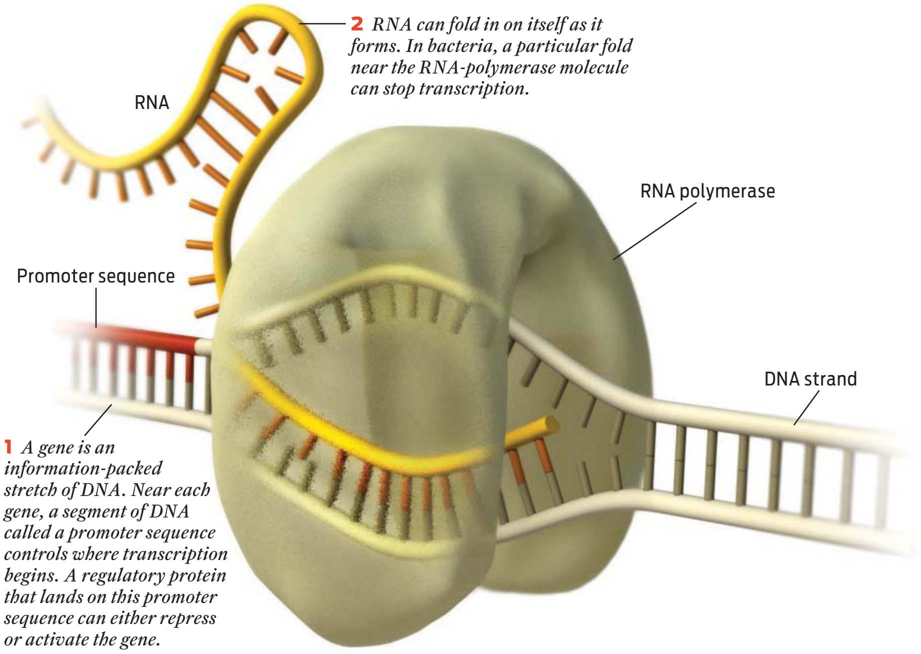
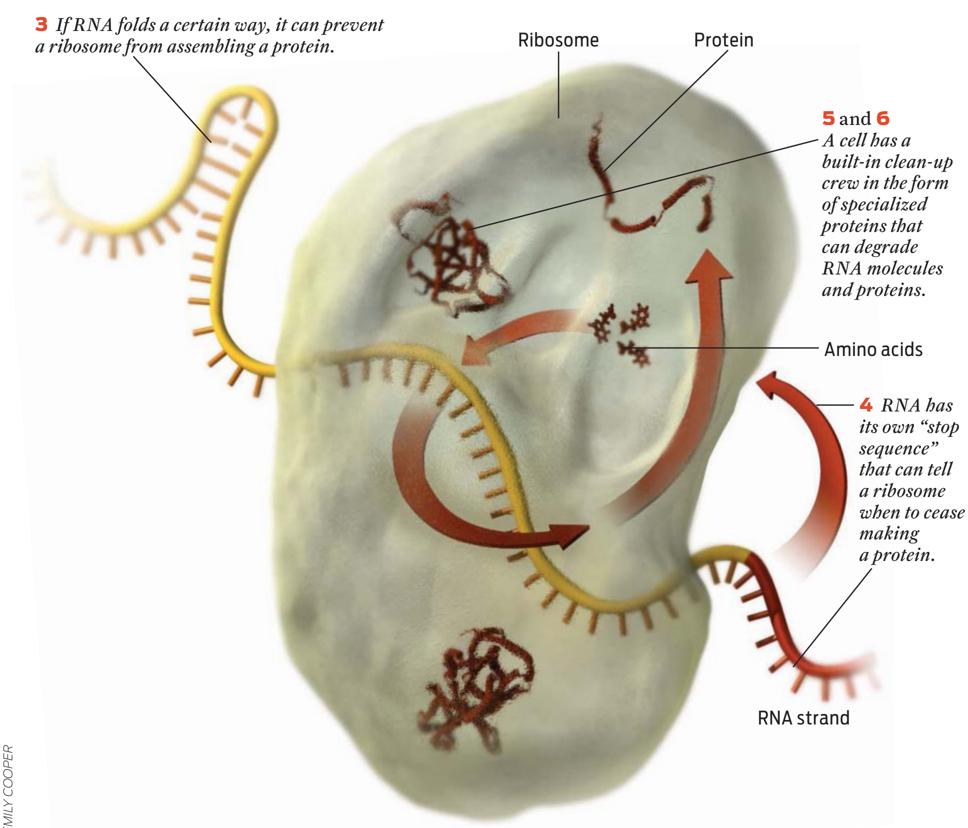
How Genes Make Proteins *(& How to Control Them)*

Transcription: DNA is converted into RNA. To accomplish this, an RNA-polymerase molecule latches onto a DNA strand, reads its genetic sequence, and assembles a complementary RNA molecule.



Translation: A molecular machine called a ribosome reads an RNA sequence and gathers together a corresponding set of amino acids. The resulting chain of amino acids then folds up to form a protein.



EMILY COOPER

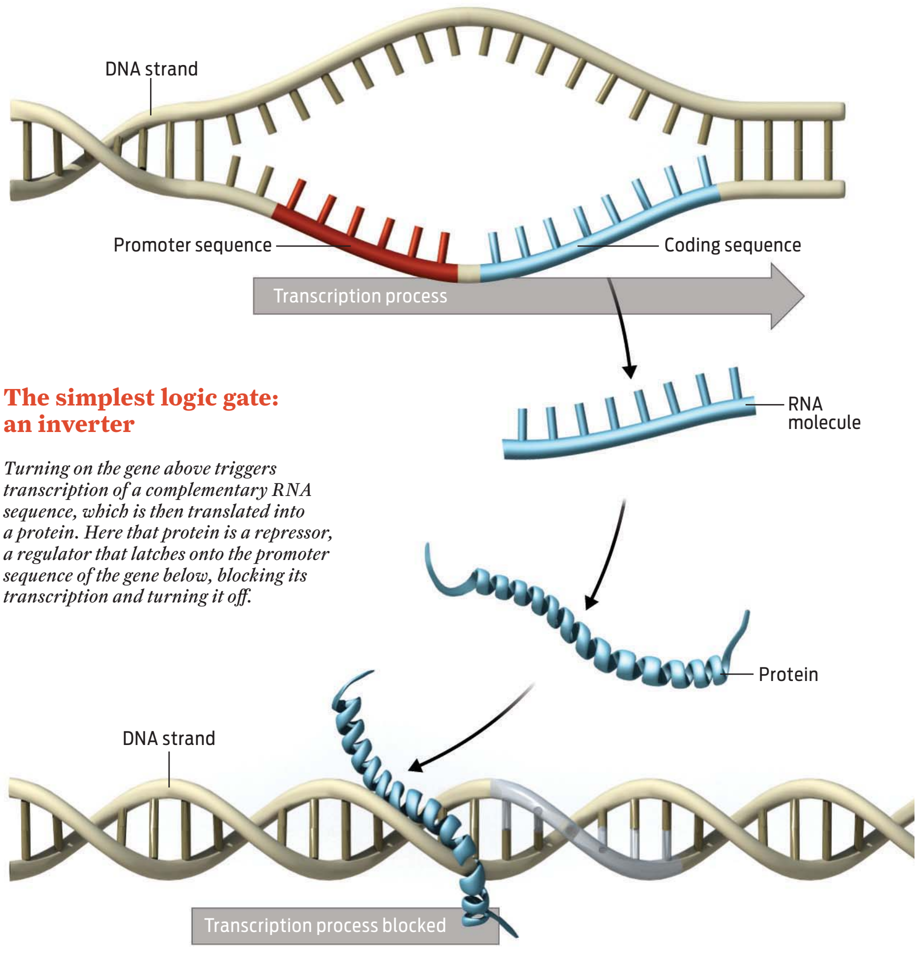
REGULATORS CAN BE COMBINED IN ONE WAY TO CREATE GENETIC LOGIC GATES AND IN ANOTHER WAY TO PROPAGATE THE SIGNALS IN GENETIC CIRCUITS

First, a small section of the double-stranded DNA spiral must be made to peel open, exposing the gene's sequence of nucleotide bases—the alphabet soup of As, Cs, Gs, and Ts you probably remember from your school days. This enables the gene's DNA sequence to be converted into RNA, a close molecular cousin of DNA. This RNA strand is said to be complementary to the original DNA strand because the new RNA's As are matched with the original DNA's Ts; its Cs are matched with Gs. (In truth, RNA uses a nucleic acid denoted by the letter U to match up with DNA's A, but that's a minor complication.) Because DNA and RNA share essentially the same nucleic-acid language, biologists call the process of converting DNA into RNA *transcription*.

Some of these RNA molecules are the end product of the gene, serving the cell with a unique function. But most are just chemical messengers, which carry instructions for the later construction of proteins. So usually the next step is to convert the genetic sequence now coded in messenger RNA into a string of amino acids, the building blocks of proteins. Because there are only 5 nucleotide bases and about 20 amino acids in cells, the language of DNA and RNA is fundamentally different from the language of proteins, which is why biologists call this next stage *translation*.

Cells use certain molecular clues to tell them when to begin and end the transcription of particular genes into messen-

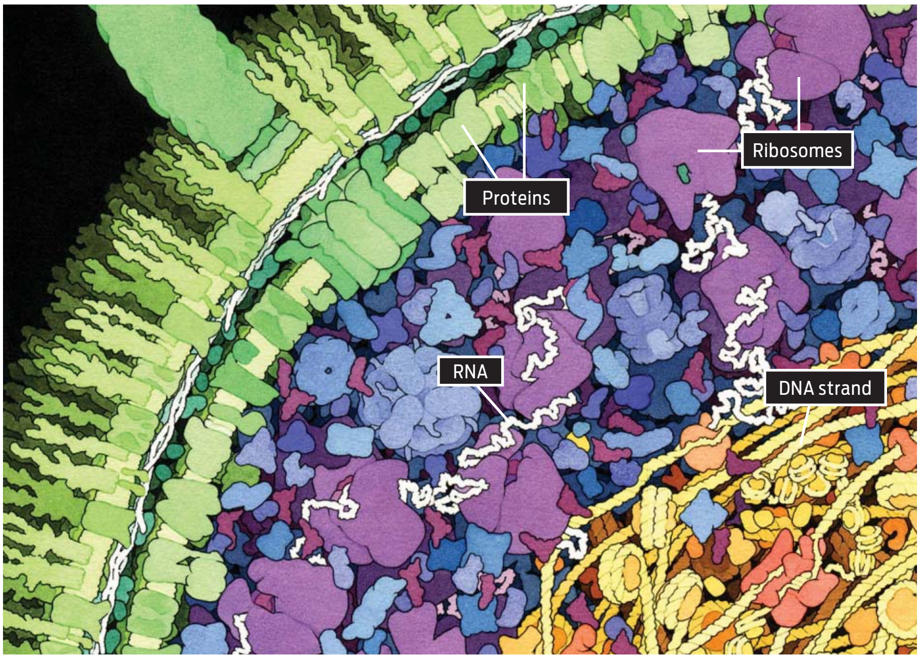
Genetic Circuitry



The simplest logic gate: an inverter

Turning on the gene above triggers transcription of a complementary RNA sequence, which is then translated into a protein. Here that protein is a repressor, a regulator that latches onto the promoter sequence of the gene below, blocking its transcription and turning it off.

But those circuits are a tangled mess. All the elements involved in expressing genes and controlling the process bounce around in the dense molecular soup inside the cell.



TOP: EMILY COOPER; BOTTOM: DAVID GOODSELL/PHOTO RESEARCHERS

GENETIC ENGINEERS WILL BE WELL POSITIONED TO SOLVE SOME OF THE WORLD'S BIGGEST PROBLEMS

ger RNA. Other molecules can trigger the breakdown of RNA after it's made. That creates three potential points of control. Particular molecular cues likewise start and stop translation. Other molecules can degrade proteins. That gives three more, for a total of six distinct knobs for adjusting how a gene is expressed.

The special biomolecules that twiddle these six knobs in the cell are called regulators. With the right ones turned up full blast, a cell will start making a particular kind of RNA and possibly protein continually, basically generating a steady current of this cellular stuff. But the buildup of a different kind of regulator molecule, called a repressor, could then halt the process, acting like a switch and cutting off that current. If this repressor is later removed, a steady current of protein molecules can once again flow into existence.

IN ELECTRONICS, currents usually travel through channels of solid metal or semiconductor, in a direction dictated by the directional push of an electric field. In the cellular world, molecules aren't so neatly localized. For the most part, they just diffuse through the watery cell interior.

Electronic circuits and cells differ in an even more fundamental way. Consider the transistors on a chip. As long as they are located a modest distance apart, they don't affect one another. So you can easily wire them together to construct logic gates and other important cir-

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cuits. A group of transistors in an AND gate will thus function without affecting a different cluster of identical transistors forming an OR gate, for example. To electrical engineers, this degree of independence is so basic they take it for granted.

Molecular regulators are more difficult to work with. Let's say you want to use one to control the creation of a particular kind of messenger RNA. Transcription of a DNA sequence into that RNA starts when a molecule called RNA polymerase binds to a special region of the DNA upstream of the genetic sequence to be transcribed. This special chunk of DNA is called a promoter sequence. After an RNA-polymerase molecule lands on a promoter sequence, it marches along the DNA strand, grabbing nucleotides floating nearby and assembling a complementary RNA sequence.

The simplest way to block this process is to prevent the RNA-polymerase molecule from moving along the DNA strand. Indeed, cells make lots of repressor proteins that bind to DNA near promoter sequences and simply sit there, preventing the movement of RNA polymerase. Such a molecule makes a perfect switch—except that it's floating around the cell in the presence of millions of other molecules. Even if the regulator molecule recognizes perfectly where it is supposed to latch onto the DNA, it still must find its target, which can take several minutes. How would you like to have to work with switches, transistorized or otherwise, that take minutes to turn off? Cells can't tolerate such delays either, so they use many copies of a repressor molecule, increasing the probability that at any given time one of them is bound to the target, turning off the gene.

This creates a problem for genetic engineers. Let's say we want to turn off one gene right now and another gene later on. We can't just splice in the target sequence for a repressor "switch" near each gene. The presence of multiple repressor molecules in the cell would turn off both. To control them independently, we'd need to use different switches—regulator molecules that work with different target sequences. Nature has devised thousands of different regulator-target pairs over billions of years of evolution. Unfortunately, most of those are very difficult to apply more generally. Synthetic biologists have, however, used some of them as building blocks for their genetic circuits and have made some intriguing biological devices with them.

For example, by engineering DNA so that two different repressor-target sequences sit side by side on a single gene, bioengineers have created a situation where that gene is expressed only when neither regulator—that is, neither input signal—is present. This is the biological equivalent of a NOR gate: If one signal or the other is present at the input, the output is not on.

You can also wire up regulators so that different genes become interdependent, the presence of one gene product controlling a second gene and so on. If you arrange those regulators—some of which repress genes and some of which activate them—so that there is feedback, you can make genetic circuits that work like flip-flops or even as oscillators, where the concentration of some molecule ebbs and flows in a regular way.

These genetic circuits were some of the early successes of synthetic biology. But their functioning is rudimentary. In the future, synthetic biologists will be able to construct far more interesting genetic wetware. Trying to do so using only the natural regulators known to biologists would, however, be like trying to build sophisticated electronic circuits from a grab bag of unlabeled parts, where you'd have to ponder over and account for the poorly documented characteristics of every single component.

For this reason, we've decided to build our own regulators. For each of the six gene-expression knobs, we want regulators that differ in the target sequences (or target molecules) they work on but are otherwise identical. To construct them, we've identified promising natural molecules to use as starting points. With these molecules, we hope to come up with a whole family of standardized, independently acting components that genetic engineers can use over and over again.

While other synthetic biologists have focused their efforts on manipulating proteins, we have concentrated on engineering RNA. Far from being just an intermediary in gene expression, RNA can adjust five of the six knobs of gene expression, with its ability to start and stop transcription, start and stop translation, and in some cases trigger its own degradation. So it's a very powerful molecule. Also, from an engineering perspective, RNA is much simpler than protein to work with because its alphabet consists of only four letters, meaning there are fewer variables. Biologists also have a better grasp of how RNA molecules fold into the complex shapes that define their function.

For a long time, synthetic biologists focused on protein repressors to make genetic circuits. The problem is that each of these protein repressors comes from a messenger RNA molecule, which adds an extra middleman in the flow of the circuit. But recently we found an RNA regulator that controls its own transcription based on whether or not another RNA molecule is present, allowing us to build circuits without proteins. So now we can operate solely with RNA. Only a couple of such molecules exist in nature, but by introducing changes in their nucleotide sequences, we've created several versions that don't affect one another's actions. We've also shown that these regulators can be combined in one way to create genetic logic gates and in another way to propagate the signals in genetic circuits, reminiscent of the electrical transistors that inspired our goals.

Our work, and that going on in other synthetic biology laboratories, will slowly build up families of regulators for adjusting the six knobs of gene expression. These families, accompanied by a set of design principles for how to wire them together (figuratively speaking), will eventually give bioengineers the means to manipulate gene expression with great precision and flexibility.

It's likely that the work synthetic biologists are doing will at first simply add to our collective grasp of the underlying science. And that's okay. But we're optimistic that given enough time, we will be able to create and control complex genetic circuits that function as designed. After that, we can start to tackle other challenges, such as constructing more specialized components to accompany our transistor-like building blocks. At that point, genetic engineers will be well positioned to solve some of the world's biggest problems—including those of food production, land use, pollution, and health. That's because we'll finally be using standardized parts and design tools, just as other kinds of engineers have been doing for a great many years. ❑

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Good things in small packages

SMARTPHONES AND TABLETS WILL INCREASINGLY OWE THEIR PROWESS TO BETTER CHIP PACKAGING

By Pushkar Apte, W.R. Bottoms, William Chen & George Scalise

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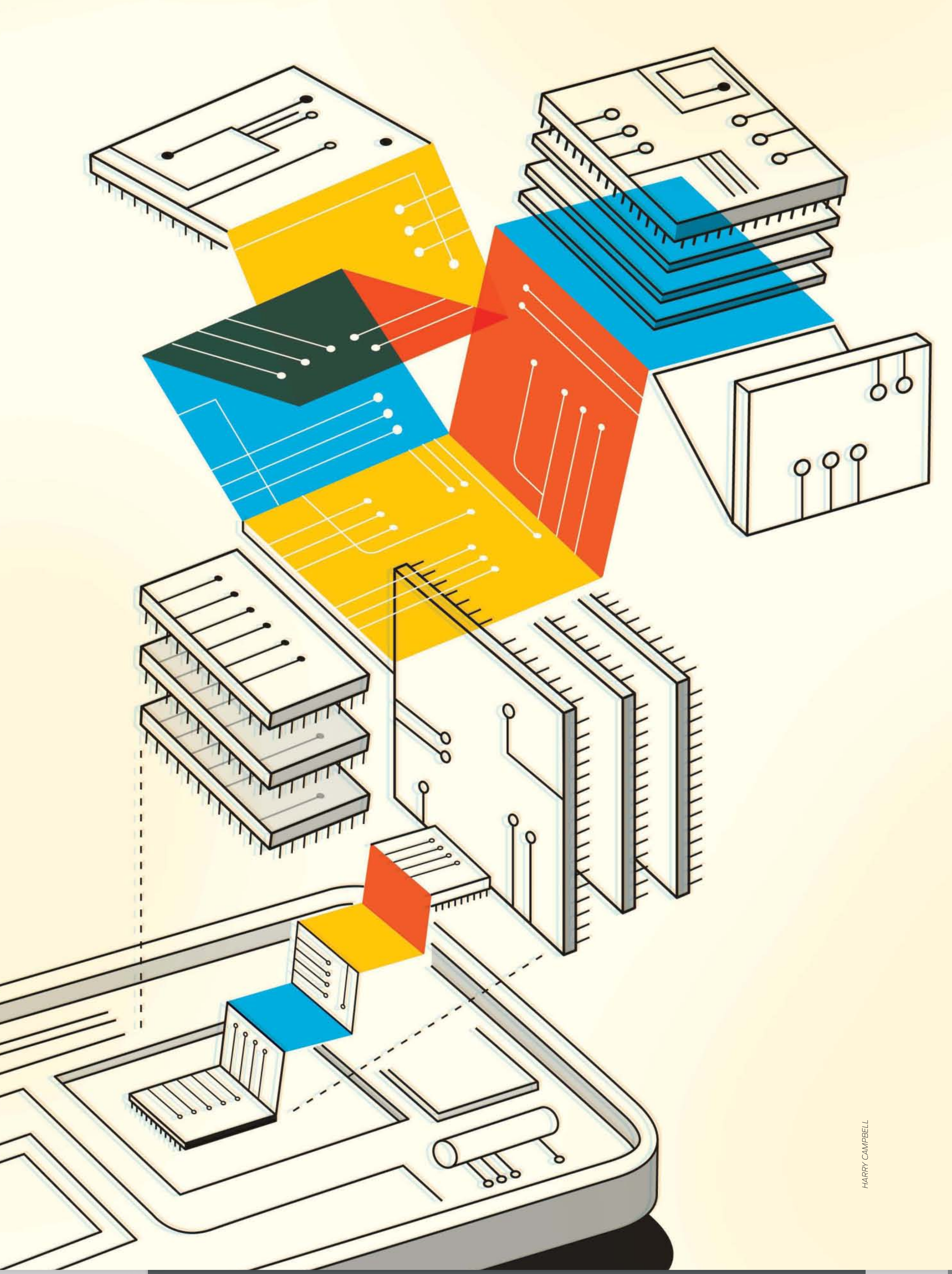


HARRY CAMPBELL

We rely on our mobile devices for an almost comically long list of functions: talking, texting, Web surfing, navigating, listening to music, taking photos, watching and making videos. Already, smartphones monitor blood pressure, pulse rate, and oxygen concentration, and before long, they'll be measuring and reporting air-pollutant concentrations and checking whether food is safe to eat.

And yet we don't want bigger devices or decreased battery life; the latest Android phones, with their vivid 4.3-inch screens, are already stretching the definition of *pocket size*, to say nothing of the pockets themselves. The upshot is that the electronics inside the devices have to do more, but without getting any larger, using more power, or costing more.

Transistor density on state-of-the-art chips continues to double at regular intervals, in keeping with the semiconductor industry's decades-old defining paradigm, Moore's Law. Today there are chips with billions of transistors at a price per chip that has headed steadily down for decades. Innovations that pack more and more circuits onto a chip will indeed continue, as will the more recent trend of putting very different functions on a single chip—for example, a microprocessor with an RF signal generator.

If we want to teach our smartphones new tricks, however, we'll have to do more than equip them with denser chips. What we will need more than ever are breakthroughs in an area not previously considered a major hub of innovation: the packaging of those chips. Packaging refers loosely to the conductors and other structures that interconnect the circuits, feed them with electric power, discharge their heat, and protect them from damage when dropped or otherwise jarred. But today, the drive to pack more functions into a small space and reduce their power requirements demands that chip packages do much more than they ever have before.

A packaged chip is a sort of puzzle, with certain fixed and well-defined pieces. Before we talk about how packaging designers are putting those pieces together in new ways, it will help to review the standard ones.

The astoundingly complex manufacturing process that leads to a chip starts with a wafer, a dinner-plate-size circle of a semiconductor material, typically silicon. Manufacturers etch, print, implant, and perform all sorts of other operations to turn a blank wafer into a grid of rectangles, each about the size of a fingernail and mind-bogglingly dense with transistors and interconnections. Sliced apart, those individual rectangles are what specialists call die. Properly packaged, each die becomes a chip. These days, many people use the terms *chip* and *die* interchangeably, but traditionally, the word *die* referred to a naked integrated circuit without packaging. We'll stick to that traditional terminology here so that we can succinctly make it clear whether we mean a packaged chip or an unpackaged die.

Inside your smartphone, you don't see naked die, of course. You see little plastic slabs of varying sizes, with scores of tiny metal prongs sticking out like insect legs, soldered onto a circuit board. The plastic slabs are the exterior of the packages. The fragile die are inside them, protected from damage during manufacture or use and connected to other chips through those prongs and the traces on the circuit boards.

These circuit boards are critical, of course, to any electronic system, but they don't actually occupy all that much space inside those systems. In fact, if you open up a smartphone today, you'll find that the amount of space allocated to electronics is rather small, so efficient use of that space is key.

Starting in the mid-1970s, designers trying to pack more functionality into a small space created systems on chips. What that means is that they designed digital and analog circuitry, memory, logic, communication, and power elements that were manufactured by a single process on a single die. This integration wasn't easy, because the processes, materials, and technologies optimal for each of these functions tend to be very different. For example, a communication or analog chip might ideally use gallium arsenide as the substrate. It might be built in 180-nanometer technology, which basically means that the smallest features of the devices on that chip measure roughly 180 nm across. A digital processor chip, on the other hand, would use a silicon substrate with 32-nm technology. Power and noise considerations also vary tremendously; the analog chip might require a much higher voltage, and noise from the digital circuitry could interfere significantly with the performance of the analog sections.

The upshot is that integration of all those functions onto a single die requires compromises in every circuit type in order to use the same process and material, thus lowering performance and increasing power consumption. A process that works for multiple types of functions is optimal for none.

So why bother to cram all those things onto one die? The main advantage is proximity, which eliminates the signal-propagation delays that can degrade performance. However, that advantage is often negated by other factors: Incredibly long and complex combinations of processes often increase costs and power consumption, while decreasing performance and yields. These trade-offs make combining disparate functions on a single chip economically unfeasible in many cases. Another barrier to this kind of integration is that hardly any companies have the necessary expertise to make every single type of circuitry needed in such a highly variegated die.

So, starting about a decade ago, designers began taking another approach—the system-in-a-package (SiP).

An SiP is a combination of integrated circuits, transistors, and other components (like resistors and capacitors) on two or more die installed within a single package. A graphics processor is a good example. Along with the processing circuitry, it has memory—both dynamic RAM and flash—as well as passive components like resistors and capacitors sitting on top of a single miniature circuit board, and the whole pile goes inside one package. With smart design integration, an SiP may contain multiple and radically different functions—incorporating, for example, microelectromechanical systems, optical components, sensors, biochemical elements, or other devices within that package. It can even contain multiple system-on-a-chip units that combine some of these functions.

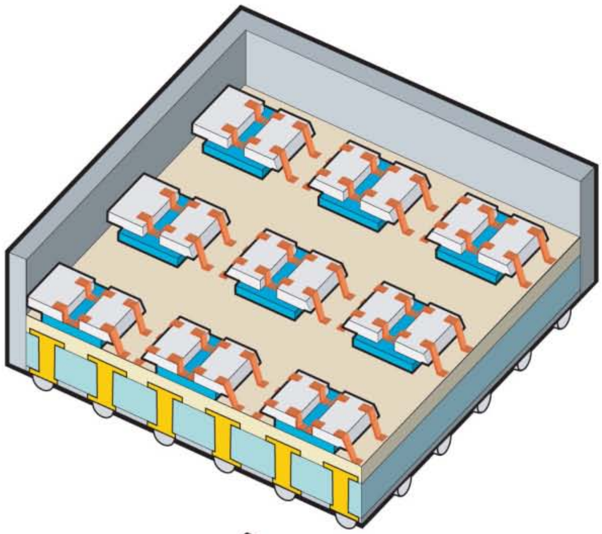
Basically, SiP lets designers mix and match components to get higher performance and get their product to market quickly while spending less on R&D, because they're using existing components. They don't have to go through a long and expensive design cycle every time they need to add a function; they can simply change part of the collection of die within the package.

The SiP approach can also enable smaller products. We all remember the bulky, single-function video cameras that tourists lugged around years ago. As those cameras got smaller, the sizes of some components—the battery, the lens, and the LCD display, for example—didn't really change much; people want big displays and lots of power. And the size of a lens is set by its aperture, image sensor, and focal length. So the burden of miniaturization falls on the electronics: When a device shrinks by 66 percent, for example (from 450 cubic centimeters in 2006 to 300 cm³ today), the electronics must shrink to a third or less of their original size.

SiP technology brings another benefit. Data paths between the processor chip and the memory chip are shorter in comparison with those on a circuit board, so

SiP, PoP, PiP

Designers have many methods of creating a system-in-a-package (SiP). The single-package SiP incorporates diverse components; multipackage variations like package-on-package (PoP) and package-in-package (PiP) incorporate additional packages into the mix.



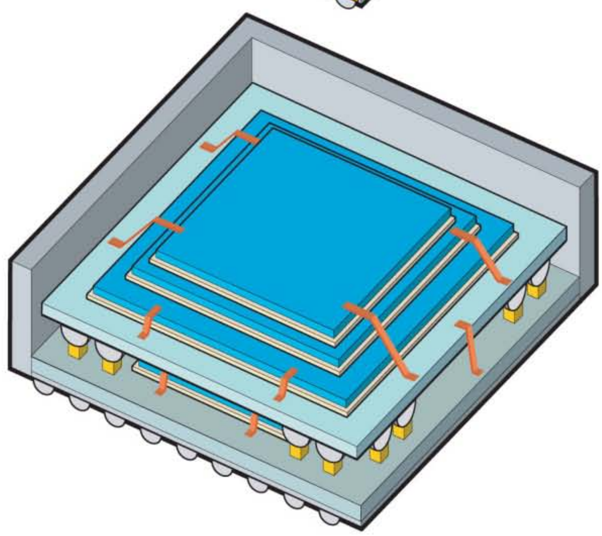
Single-package SiP

ORIGINATED EARLY 1990s

Advantages: Can contain the largest number of different component types

Disadvantages: The complexity may make testing more difficult

Typical uses: Microcontrollers, graphics processors, high-end networking products



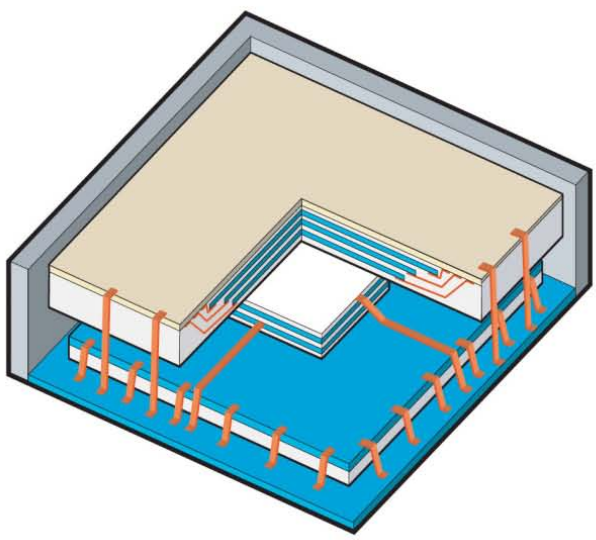
Package-on-package (PoP)

ORIGINATED MID-2000s

Advantages: Components easier to test before stacking

Disadvantages: Hard to test after stacking

Typical uses: Digital still cameras, high-end smartphones, tablet computers



Package-in-package (PiP)

ORIGINATED MID-2000s

Advantages: Can give the best possible performance for some applications at the lowest cost, using a small number of chips

Disadvantages: Less ability to combine components from different suppliers; difficult to test

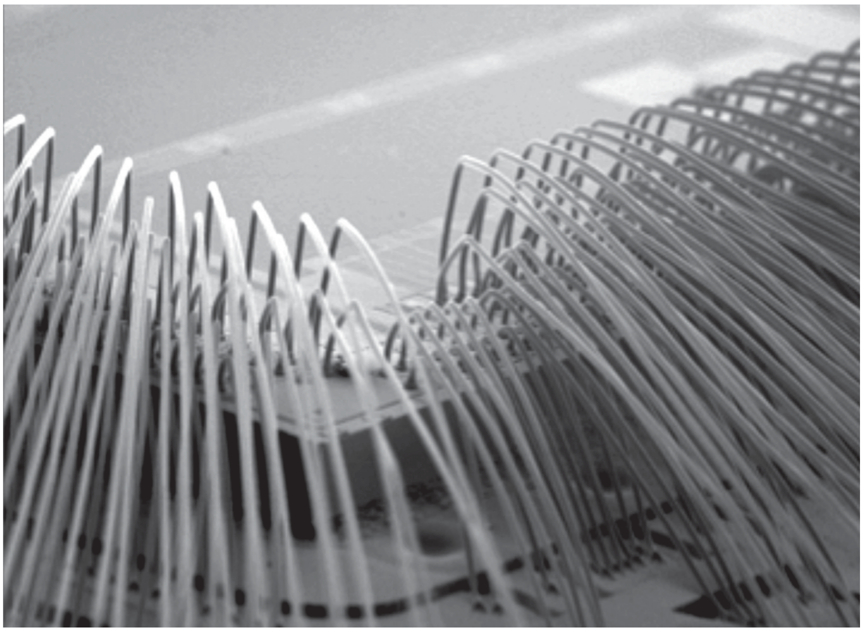
Typical uses: High-end smartphones

GEORGE RETSECK

data flow is faster and noise is reduced. With less distance to travel, it takes less power to get there—another plus. This reduction in size and increase in performance are the driving forces behind the continued evolution of SiP architectures.

There's more than one way to build a system-in-a-package. One of them is called package-on-package (PoP). Remember that circuit board crammed with chips? It looks a little like a suburban office park seen from the air. Well, what better way to cram in more office space than to swap out some one-story buildings for multistory replacements? That's what package-on-package designers are doing. They pack a lot of circuitry into a small volume by stacking one set of connected die on top of another set—flash and DRAM components, for example, on top of an application-specific IC—and then putting them inside a single package so that product designers and manufacturers can deal with them as single units. The sets stack like Lego blocks, typically with logic on the bottom and memory on top. Such structures are adaptable—manufacturers, when necessary, can vary the memory density by swapping out the piece of the stack that holds the memory components, for example. And each of the sets within the package can be tested individually before stacking. After stacking, however, testing becomes more difficult. And manufacturers will worry about possible warping of the miniature circuit boards and die, which would reduce the yield during assembly.

So PoP systems are a little pricey and therefore used only for products whose prices can include a premium for better performance in a smaller, low-power package. Manufacturers of high-end networking products were early adopters of this approach; manufacturers of digital still cameras and cellphones have since joined them. Smartphones and, more recently, tablet computers are using PoPs mainly to integrate application-specific ICs with memory. PoP continues to evolve and will likely migrate into other products further down the consumer-electronics food chain.



TIES THAT BIND: Fanning wires out from all sides of a chip and making those wires thinner gives designers more electrical paths to choose from.

Package-in-package (PiP) is another variant of SiP. Instead of just naked die and other components piled onto miniature circuit boards inside a single package, PiP adds packaged die—in other words, chips—into the mix. So PiP puts chips within chips. Semiconductor companies choose this option for business reasons as much as for technical ones—it forces product manufacturers to buy multiple subsystems from the same chip manufacturer. PiP integrates more functions and can improve performance beyond that of PoP systems, but it is less flexible in combining different devices, like memory chips, from different suppliers. It's also hard to test. In some mobile applications—for example, the most advanced smartphones—manufacturers gladly accept these drawbacks because PiP designs can cram even more into a smaller space. But they haven't caught on as widely as the PoP approach.

In all these packaging schemes, the most important consideration is the electrical connections between the multiple die and the miniature circuit boards that link them. The traditional and cheapest technology used for these connections is wire bonding, which is in about 80 percent of the packages produced today. Wires connect terminals on an individual chip to the little circuit board inside the package. Then electrical paths on that circuit board route signals among chips and to the leads that extend from the package, enabling it to be connected to other devices within a system.

Despite repeated predictions that wire-bond technology has reached its practical physical limit, it continues to reinvent itself: In the past few years, manufacturers reduced the wire diameter to 15 micrometers to enable them to cram more wire terminals onto the precious real estate of a chip's surface. They also began changing the wire materials from gold to copper, in response to the skyrocketing cost of gold.

In a conventional wire-bond connection between two chips, the electrical path runs from the closely spaced terminals at the edge of the chip to terminals on the substrate. As the chip shrinks, so does the distance between the individual terminals, and it becomes tricky for designers to avoid short circuits and to keep the wires far enough apart to minimize cross talk.

Nevertheless, many innovations are extending the life of this technology. Some manufacturers, for example, are replacing single rows of wires with multiple rows on the four edges of the chip to give designers more options for electrical paths.

Alternatively, some designers have eliminated the wires altogether and replaced them with "bumps" of solder, gold, or copper. This approach earned the name flip-chip, because the side of the chip with the bumps must be flipped face down to connect with the bumpy side of the chip below or the underlying circuit board. As you can imagine, a small bump of metal is smaller and shorter than a long wire and therefore can conduct a signal much faster and at higher bandwidths. However, this advantage comes at a cost—increasing the overall price of

ASE GROUP

the package to 1.5 to 5 times that of a wire-bond version. Not surprisingly, this technology has also gravitated toward industries that need high performance and will pay for it. It is now standard for high-speed and high-bandwidth microprocessors and graphics processors because of its shorter delay time.

A newcomer to the package scene is the wafer-level chip-scale package. This technology is essentially a package without a package—the naked die has extremely tiny solder balls on its active side, allowing it to connect directly to a circuit board. These die are fragile, so to date this process can be used only for very tiny die, and even these typically need to be further protected with a coating on one side. The vast majority of smartphone manufacturers are beginning to embrace this approach.

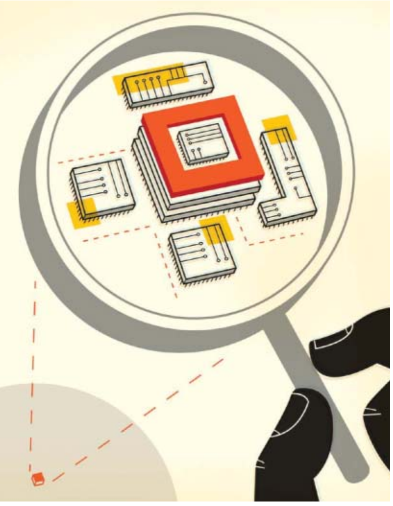
Designers have found another way to make SiP devices as small as possible—one that might seem obvious. They simply make the wafer thinner—taking a wafer that is, say, a little over 700 µm thick and reducing it to perhaps 100 or even 50 µm or less. Because the size of the wafer eventually determines the size of the package, and therefore the size of that device you're carrying in your pocket, that change can make a big impact.

Mechanical grinding is the most popular way to thin a wafer. It's just what you'd expect: Manufacturers physically grind the wafer down, typically by rolling it through a slurry of water and abrasive particles or rubbing it with diamond particles embedded in a resin. There are lots of other ways to thin a wafer, including chemical mechanical polishing, which smooths surfaces with the combination of chemical and mechanical forces, and chemical etching, which uses chemical liquids or vapors to remove some of the wafer material.

With the trend toward smaller packages, manufacturers are making die thinner than was ever thought possible. For example, one manufacturer recently privately demonstrated a flash memory die 10 µm thick and a tiny RF device measuring 50 by 50 by 5 µm.

SiPs are the best way to pack very different functions into a single electronic device. In the future, the individual pieces in an SiP could be as diverse as RF antennas, photodiodes, and drug delivery tubes—perhaps even a protein layer that could allow the chip to connect with human tissue.

Repackaging the Semiconductor Business



HARRY CAMPBELL

Fabless design firms and foundries that don't design their own chips—that split has become more and more distinct in the semiconductor industry. But recent advances in packaging technology that have made the package as important as the individual die are about to bridge this chasm.

Going fabless made a lot of sense for design companies unable to keep up with the bleeding edge of process evolution. A new state-of-the-art digital fab may cost US $6 billion to $9 billion, and it may cost several hundreds of millions of dollars for process development at the 45-nanometer and 32-nm feature sizes, typical in today's processor and memory chips. These costs will only increase more as the industry moves to sub-22-nm feature sizes.

Simply designing such a chip is enormously expensive: A digital integrated circuit with billions of transistors costs $50 million to $100 million to design. A large part of this cost is incurred in verifying that the billions of little transistors and all their interconnections actually do what they are supposed to do. This high design cost affects all semiconductor companies regardless of their business model, be it integrated or fabless.

Packaging technology may allow semiconductor companies to continue to innovate affordably. It is easier to separately verify die that perform different functions than to verify a single complex die. So packaging different die together in a compact and power-efficient manner makes good business sense, given the lower cost and shorter time to market. Companies are investing increasingly in packaging, whether it be by hiring packaging specialists, getting involved in partnerships, or funding start-ups.

As a result, we in the semiconductor business are seeing a virtual reintegration, reversing nearly two decades of atomization, during which an integrated industry split up into fabless design houses, process foundries, packaging houses, toolmakers, and so forth.

This reintegration is definitely virtual. That is, the various companies are working much more closely together, trusting each other, collaborating, and sharing information across company and national boundaries, but it is not likely that the functions will reassemble again under one corporate roof, at least for most of the industry. *—P.A., W.R.B., W.C. & G.S.*

But we're not quite there yet. Putting such complex devices into a single package will require new materials and control of their interactions on the nanometer scale—and perhaps even on the molecular scale. It won't be easy. There will be tough competition as consumers demand smaller and smaller devices that do more and more. Designers are now investigating taking packageless packaging beyond simply attaching naked die to circuit boards; they are beginning to attach naked die directly to each other in three dimensions. Some manufacturers are already making simple versions of these 3-D modules, but this technology has a long way to evolve before it can become a staple of the manufacture of high-volume commercial products.

All these packaging innovations are remarkable, but the real impact has to be measured by what they enable in the real world—and how they will change society. Electronics are woven into the fabric of our lives and are beginning to be woven, literally, into the clothes we wear. Increasingly, they will be implanted in our bodies as well. Pacemakers, defibrillators, and microfluidic pumps for drug delivery are in use; biosensors and other implantable devices that can send data to external computers are on the way. Devices that may allow control of epilepsy, Parkinson's disease, and migraines are already in clinical trials. Future forms of packaging will not only have to protect the electronics from the environment but also shield a sensitive environment—the human body—from the electronics. These innovations will improve our work, our health, our play, and even our longevity. ❑

TELL US WHAT YOU THINK at http://spectrum.ieee.org/packaging0311

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SUPERCONDUCTIVITY'S FIRST CENTURY

IN THE 100 YEARS SINCE SUPERCONDUCTIVITY WAS DISCOVERED, ONLY ONE WIDESPREAD APPLICATION HAS EMERGED

By PRADEEP HALDAR & PIER ABETTI

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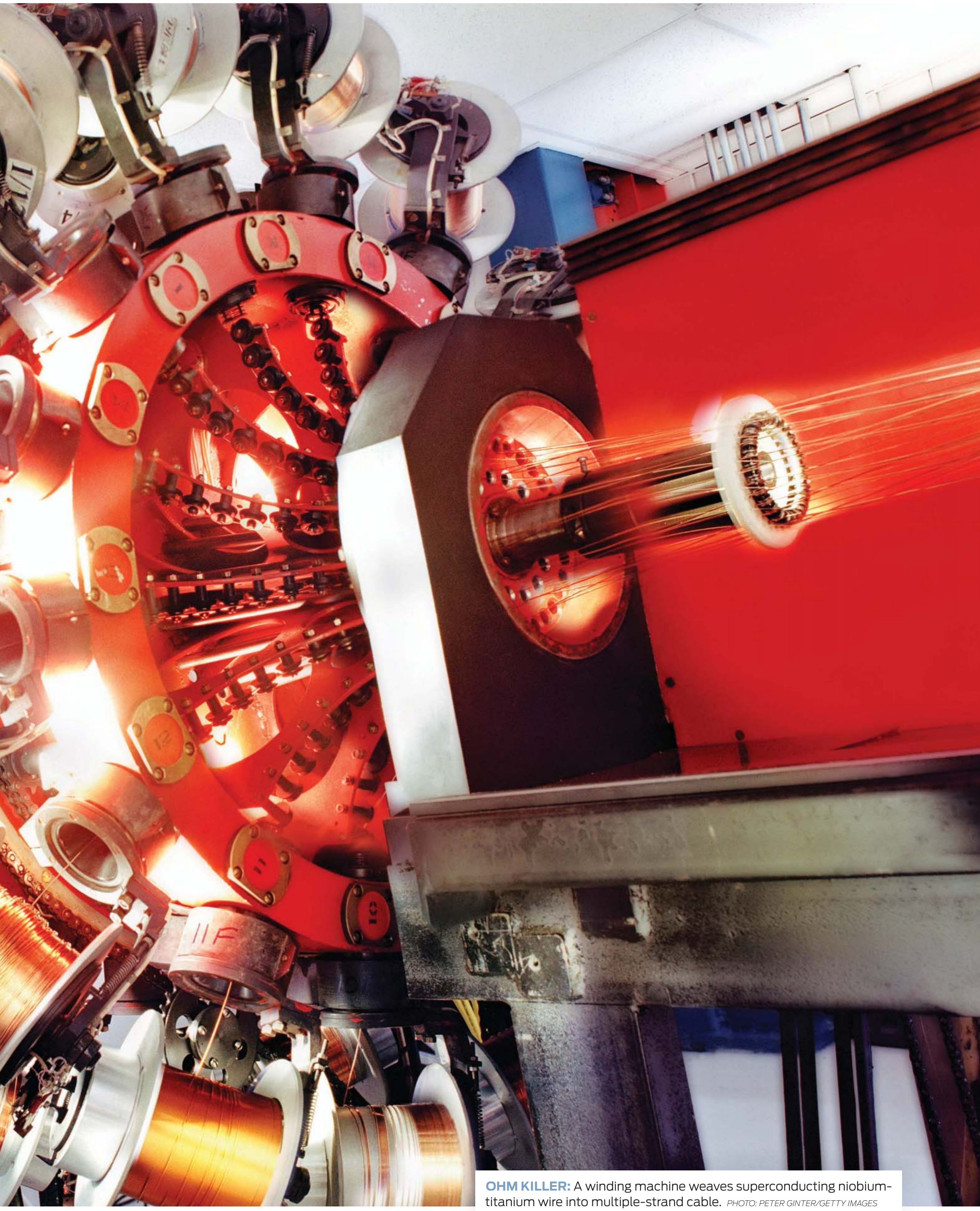

OHM KILLER: A winding machine weaves superconducting niobium-titanium wire into multiple-strand cable. *PHOTO: PETER GINTER/GETTY IMAGES*

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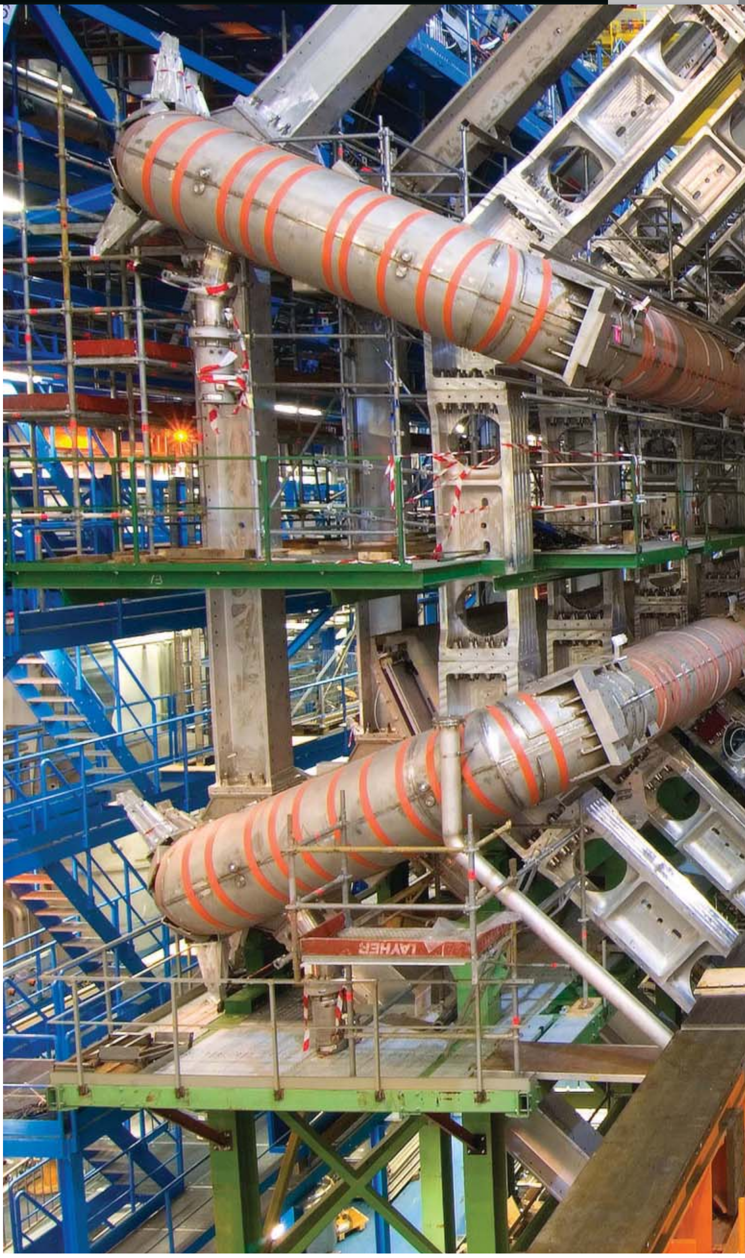


Absolute zero, as the name suggests, is as cold as it gets.

In 1848, Lord Kelvin, the great British physicist, pegged it at –273 °C. He thought that bringing something to this temperature would freeze electrons in their tracks, making what is normally a conductor into the perfect resistor. Others believed that electrical resistance would diminish gradually as a conductor cooled, so that by the time it reached absolute zero, all vestiges of resistance would disappear. It turns out that everybody was wrong.

Heike Kamerlingh Onnes, professor of physics at Leiden University, in the Netherlands, found the answer early in 1911 by measuring the resistance of mercury that was frozen solid and chilled to within a few degrees of absolute zero. He found that the resistance declined in proportion to the temperature all the way down to 4.3 kelvins (4.3 °C above absolute zero), at which point it fell abruptly to zero. Onnes first thought he had a short circuit. It took him a while to realize that what he had was, in fact, the makings of a Nobel Prize—the discovery of superconductivity.

Since then, physicists have sought to understand the quantum-mechanical origins of superconductivity, and engineers have tried to make use of it. While scientific efforts in this area have been rewarded by no fewer than seven Nobel prizes, all commercial applications of superconductivity have pretty much fizzled except one, which came out of the blue: magnetic resonance imaging (MRI).

Why did MRI alone pan out? Can we expect to see a second widespread application anytime soon? Without a crystal ball, it's hard to know, of course, but reviewing the evolution of superconductivity's first century offers some interesting clues about what we might expect for its second.

ONNES HIMSELF expected that superconductivity would be valuable because it would allow for the transmission of electrical power without a loss of energy in the wires. Those early hopes were, however, dashed by the observation that there were few materials that became superconducting at temperatures above 4 K and that those materials stop superconducting if you try to pass much current through them. This is why for the next five decades most of the research in this field was centered on finding materials that could remain superconducting while carrying appreciable amounts of current. But that was not the only requirement for practical devices. The people working on them also needed to find superconducting materials that weren't too expensive and that could be drawn into thin, reasonably strong wires.

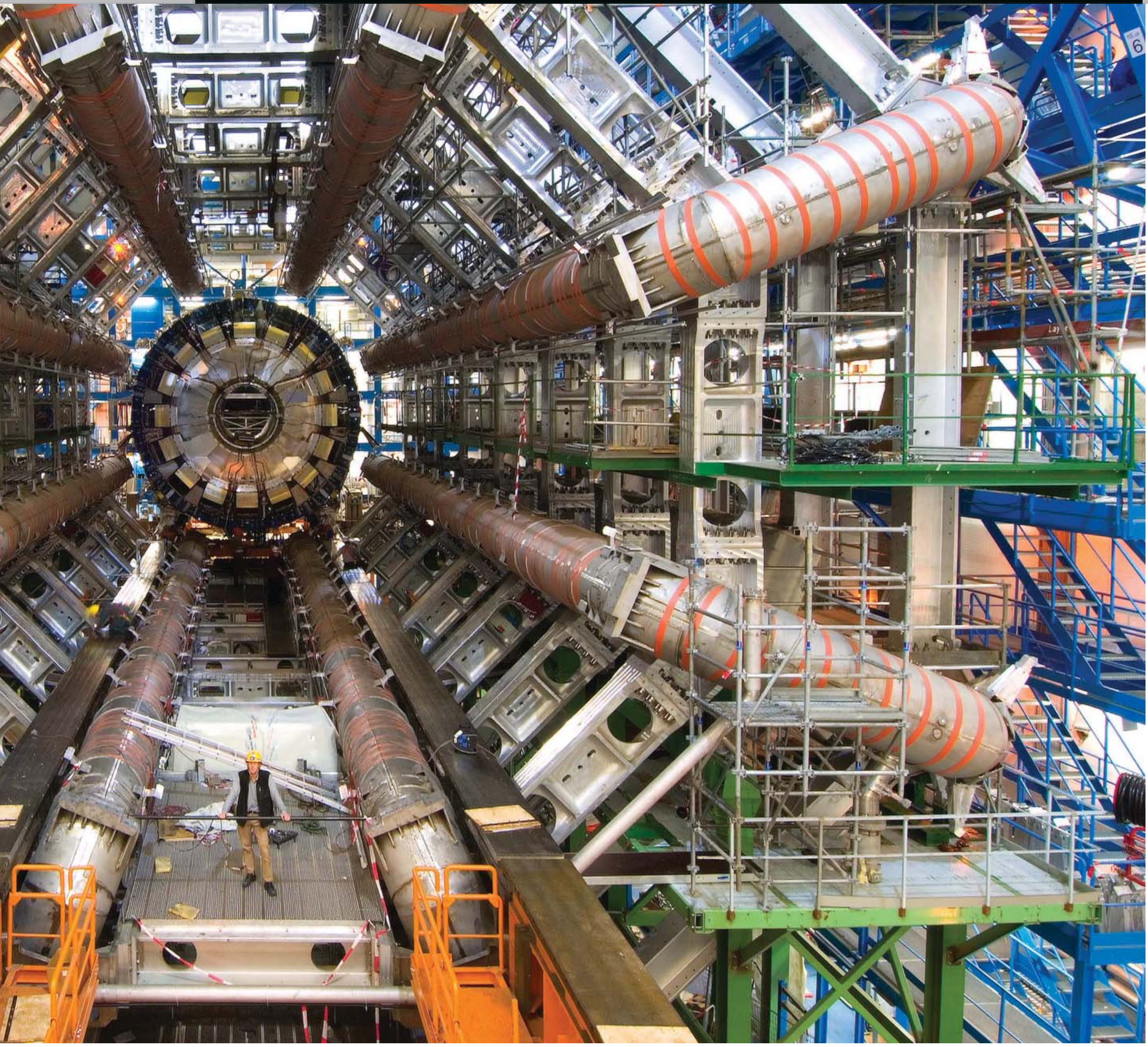
In 1962 researchers at Westinghouse Research Laboratories, in Pennsylvania, developed the first commercial superconducting wire, an alloy of niobium and titanium. Soon after, other researchers,

100 YEARS OF SUPERCONDUCTIVITY

The technology languished for a half century and then found only one widespread use—MRI. What's next?

1911: Dutch physicist Heike Kamerlingh Onnes discovers SUPERCONDUCTIVITY.

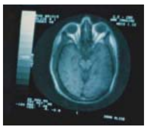
TOP: MAXIMILIEN BRICE/CERN; BOTTOM CENTER: THE NOBEL FOUNDATION



2006: World's largest SUPERCONDUCTING MAGNET, a component in CERN's Large Hadron Collider, is powered up.

1961: NIOBIUM-TIN is found to remain superconducting with high currents.

1962: Westinghouse develops the first commercial superconducting wire of NIOBIUM AND TITANIUM. Others use this alloy to make superconducting magnets.



1980: The first commercial MRI SCANNERS are constructed, using superconducting magnets.

1986: Physicists at IBM Research–Zurich devise a CERAMIC that displays superconductive properties at relatively high temperatures.

1987: Four MIT professors found AMERICAN SUPERCONDUCTOR CORP. to take advantage of the new high-temperature superconductors.

2011: The Tokyo Electric Power Co. will test a SUPERCONDUCTING POWER CABLE at its Asahi substation.

at the Rutherford Appleton Laboratory, in the United Kingdom, improved it by adding copper cladding. At the time, the most promising application appeared to be in the giant magnets physicists use for particle accelerators, as superconducting magnets were able to offer much higher magnetic fields than ones made from ordinary copper wire.

With this and other similar applications in mind, one of us (Abetti) and his fellow scientists and engineers at the General Electric Co. location in Schenectady, N.Y., succeeded within months in building the world's first 10-tesla magnet using superconducting wire. Although a scientific and technical triumph, that magnet was a commercial failure. Development costs ran to more than US $200 000, well above the fixed-price contract of $75 000 that Bell Telephone Laboratories had paid GE for this magnet, which was to be used for basic research in materials science.

Around this time, engineers at GE and elsewhere demonstrated some other practical applications for superconductors, such as for the windings of large generators, motors, and transformers. But superconducting versions of such industrial machinery never caught on. The problem was that the existing equipment was technologically mature, having already achieved high electrical efficiencies. Indeed, motors, generators, and transformers were practically commodities, with reliability and low cost being what customers most cared about.

That seemingly left only one niche open: superconducting cables for power transmission in areas where overhead lines could not be used—over large bodies of water and in densely populated areas, for example. While the promised gains in efficiency were attractive, the need for expensive and unreliable cooling vessels for the cables made them a dicey proposition.

GE's management considered the market for superconductivity's one proven product—magnets—too small and uncertain. But one of the researchers at GE wouldn't take no for an answer. In 1971, Carl Rosner created an independent spin-off, Intermagnetics General Corp., or IGC, in Latham, N.Y., which made and sold laboratory-size magnets and received government research-and-development grants. The new company was immediately profitable.

SCAN FANS: General Electric rolled out its first magnetic resonance imaging scanners in the early 1980s. Those and other makers' MRI systems required powerful electromagnets, a perfect application for superconductivity. *PHOTO: SCHENECTADY MUSEUM/SUITS-BUECHE PLANETARIUM*

At about this time, Martin Wood, a senior research officer at the University of Oxford's Clarendon Laboratory, and his wife, Audrey, also decided to try to turn superconductivity into a business. In addition to design and consulting work, their newly hatched company, Oxford Instruments, developed and marketed magnets for research purposes, building the first high-field superconducting magnet outside the United States in March of 1962. By 1970, Oxford Instruments had 95 employees.

The 1970s saw the emergence of a few other start-ups that used superconductivity for building such things as sensitive magnetometers. And various research efforts were spawned to explore other applications, including superconductive magnets for storing energy and for levitating high-speed trains. But GE, Philips, Siemens, Westinghouse, and other big players still showed little interest in superconductivity, which, in the view of the managements of these companies, seemed destined to remain a sideshow. They were, however, proved very wrong toward the end of the decade, when a stunning new use for superconducting magnets appeared on the scene: MRI.

MRI was an outgrowth of an analysis technique chemists had long been using called nuclear magnetic resonance (NMR), which itself has since created a significant market for superconducting magnets. There were hints as far back as the 1950s that the NMR signals emanating from different points within a magnet could be distinguished, but it wasn't until the late 1970s that it became apparent that medically relevant images could be made this way.

THE ADVENT of medical imagers that required a person to be immersed in an intense magnetic field brought a swift change in the business calculus at GE, where managers suddenly smelled a billion-dollar market. They knew that the technical risk involved in making the superconducting magnets required for MRI was low—after all, GE's spin-off IGC had already fabricated comparable products. They knew also that GE could take advantage of its long-established presence in the medical-imaging market, for which it had produced X-ray machines and, more recently, computerized axial tomography scanners. Also, by this time GE had a more entrepreneurial climate, which encouraged the company's operating units to take risks.

This really was superconductivity's golden moment, and GE seized it. In 1984 the company rolled out its first MRI system, and by the end of the decade, GE could boast an installed base of over 1000 imagers. Although it constructed its MRI magnets in-house, GE used niobium-titanium wire manufactured by IGC.

Meanwhile, IGC learned to build MRI magnets of its own, which it sold to GE's competitors. And with a budget of only $5 million, IGC succeeded in building MRI scanners that were functionally equivalent to those GE, Hitachi, Philips, Siemens, and Toshiba were then selling. IGC, however, lacked the marketing clout and reputation within the health-care industry to compete with these multinational giants. So it fell back on its main business, manufacturing superconducting MRI magnets, which it sold primarily to Philips.

Although there were a few attempts at the time to find other commercial uses for superconductivity—in X-ray photolithography or for separating ore minerals, for example—MRI provided the only substantial market. It was around this time, though, that yet another scientific breakthrough put superconductivity back on everyone's radar.

IN 1986, Karl Alexander Müller and Johannes Georg Bednorz, researchers at IBM Research–Zurich, concocted a barium-lanthanum-copper oxide that displayed superconductive properties at 35 K. That's 12 or so kelvins warmer than any other superconductive material known at the time. What made this discovery even more remarkable was that the material was a ceramic, and ceramics normally don't conduct electricity. There had been hints of superconducting ceramics before, but until this time, none of them had shown much promise.

Müller and Bednorz's work triggered a flurry of research around the world. And within a year scientists at the University of Alabama at Huntsville and the University of Houston found a similar ceramic compound that showed superconductivity at temperatures they could attain using liquid nitrogen. Before, all superconductors had required liquid helium—an expensive, hard-to-produce substance—for cooling. Liquid nitrogen, however, can be made from air without that much effort. So the new high-temperature superconductors, in principle, threw the door wide open for all sorts of practical uses, or at least they appeared to.

PREVIOUS PAGE: LEFT: SUPERPOWER/INTERMAGNETICS GENERAL CORP. ARCHIVES; RIGHT: SCHENECTADY MUSEUM/SUITS-BUECHE PLANETARIUM

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The discovery of high-temperature superconductors sparked tremendous publicity—which in retrospect is easy to see was hype. *Newsweek* called it a dream come true. The cover of *Time* magazine showed a futuristic automobile controlled by superconducting circuits. *BusinessWeek* declared, "Superconductors! More important than the light bulb and the transistor" on its cover. Many sober scientists and engineers shared this enthusiasm. Among them were Yet-Ming Chiang, David A. Rudman, John B. Vander Sande, and Gregory J. Yurek, the four MIT professors who founded American Superconductor Corp. during this time of feverish excitement over the new high-temperature materials.

Despite all the hoopla, managers at Oxford Instruments, one of the few companies with any real experience using superconductivity at that point, had a dim view of the prospects for the high-temperature ceramics. For the most part, they decided to stick to their former course: working to improve the company's low-temperature niobium-titanium wire and making incremental improvements in its MRI magnets. Oxford Instruments put only a small effort into studying the new high-temperature superconductors.

The management at IGC, which at the time included one of us (Haldar), saw more promise in the new materials and worked hard to see how they could commercialize them for such things as electrical transmission cables, industrial-scale current limiters, energy-storage coils, motors, and generators. American Superconductor, which went public in 1991, did the same.

It took more than a decade to do, but IGC eventually developed a high-temperature superconducting wire and in collaboration with Waukesha Electric Systems, in Wisconsin, built a transformer with it in 1998. In 2000, IGC and Southwire, of Carrollton, Ga., demonstrated a superconducting transmission cable. Soon after, Haldar and his IGC colleagues established a subsidiary, called IGC-SuperPower, to develop and market electrical devices based on high-temperature superconductivity.

In 2001, American Superconductor tested a superconducting cable for the transmission of electrical power at one of Detroit Edison's substations. In 2006, SuperPower connected a 30-meter superconductive power cable

SCHENECTADY MUSEUM/SUITS-BUECHE PLANETARIUM

Q+A: Nobelist Ivar Giaever

Pier Abetti: You received the Nobel Prize in Physics in 1973 for your theoretical work on the origins of superconductivity. The only major commercial use of superconductivity so far has been MRI. Why is that?

Ivar Giaever: Because there were no other practical ways to obtain the high magnetic fields needed (up to 7 tesla).

Looking toward the future, say, within the next 20 years, do you foresee any new industrial breakthroughs with superconductivity? In what fields?

Superconducting tunnel junctions are faster than transistors, but superconductive computers would require expensive cooling. Because of that, the first applications will probably be for supercomputers. But those would be exceedingly difficult to build. They might never happen. Research work should continue on high-temperature superconductive materials.

to the grid near Albany, N.Y. American Superconductor carried out an even more impressive demonstration of this kind in 2008, when it threw the switch for a 600-meter-long superconducting power cable used by New York's Long Island Power Authority, part of a program funded by the U.S. Department of Energy.

While all these projects were technically successful, they were merely government-sponsored demonstrations; electric utilities are hardly clamoring for such products. The only commercial initiative now slated to use superconducting cables is the proposed Tres Amigas Superstation in New Mexico, an enterprise aimed at tying the eastern, western, and Texas power grids together in one spot. Using superconducting cables would allow the station to transfer massive amounts of power, and because these lines can be relatively short, they wouldn't be prohibitively expensive.

But Tres Amigas is an exception. For the most part, the electric power industry has shown a stunning lack of interest in superconductors, despite the many potential benefits over conventional copper and aluminum wire: three to five times as much capacity within a given conduit size, half the power losses, no need for toxic or flammable insulating materials. With all those advantages, you might well wonder why this technology hasn't taken the electric-power industry by storm over the past two decades.

One reason (other than cost) may stem from the changing nature of electric utilities, which in many countries have lost their former monopoly status. These companies are by and large reluctant to make substantial investments in infrastructure, especially for projects that don't promise a quick return [see "How the Free Market Rocked the Grid," *IEEE Spectrum*, December 2010]. So the last thing many of them desire is to assume the risk of adopting anything as radical as superconductive cables, generators, or transformers.

IT MAY be that superconductivity just needs time to mature. Plenty of technologies work that way. Perhaps the next generation of wind turbines will sport superconducting generators in their nacelles, an application that American Superconductor is working toward. A better bet in our view, though, is that superconductivity will remain limited to applications like MRI, where it's very difficult to build something any other way.

What will those applications be? A ship that cuts through the waves using superconducting magnetic propulsion instead of propellers? Unlikely: Japanese engineers built such a vessel in 1991, and it's long since been mothballed. An antigravity device that can make living creatures float? Probably not: The 2010 Nobel laureate Andre Geim demonstrated that this could be done in 1997, and it hasn't been put to any real use. A magnetically levitated train that can top 580 kilometers per hour? Japanese engineers built one in 2003; yet few rail systems are giving up on wheels. A supercooled microprocessor that can run at 500 gigahertz? Perhaps: IBM and Georgia Tech captured that speed record in 2007, but it would be hard to make such a setup practical.

We certainly don't know what's ahead. But we suspect that the next big thing for superconductivity, whatever it is, will, like MRI, take the world by surprise. ❑

JOIN THE DISCUSSION at http://spectrum.ieee.org/superconductivity0311.

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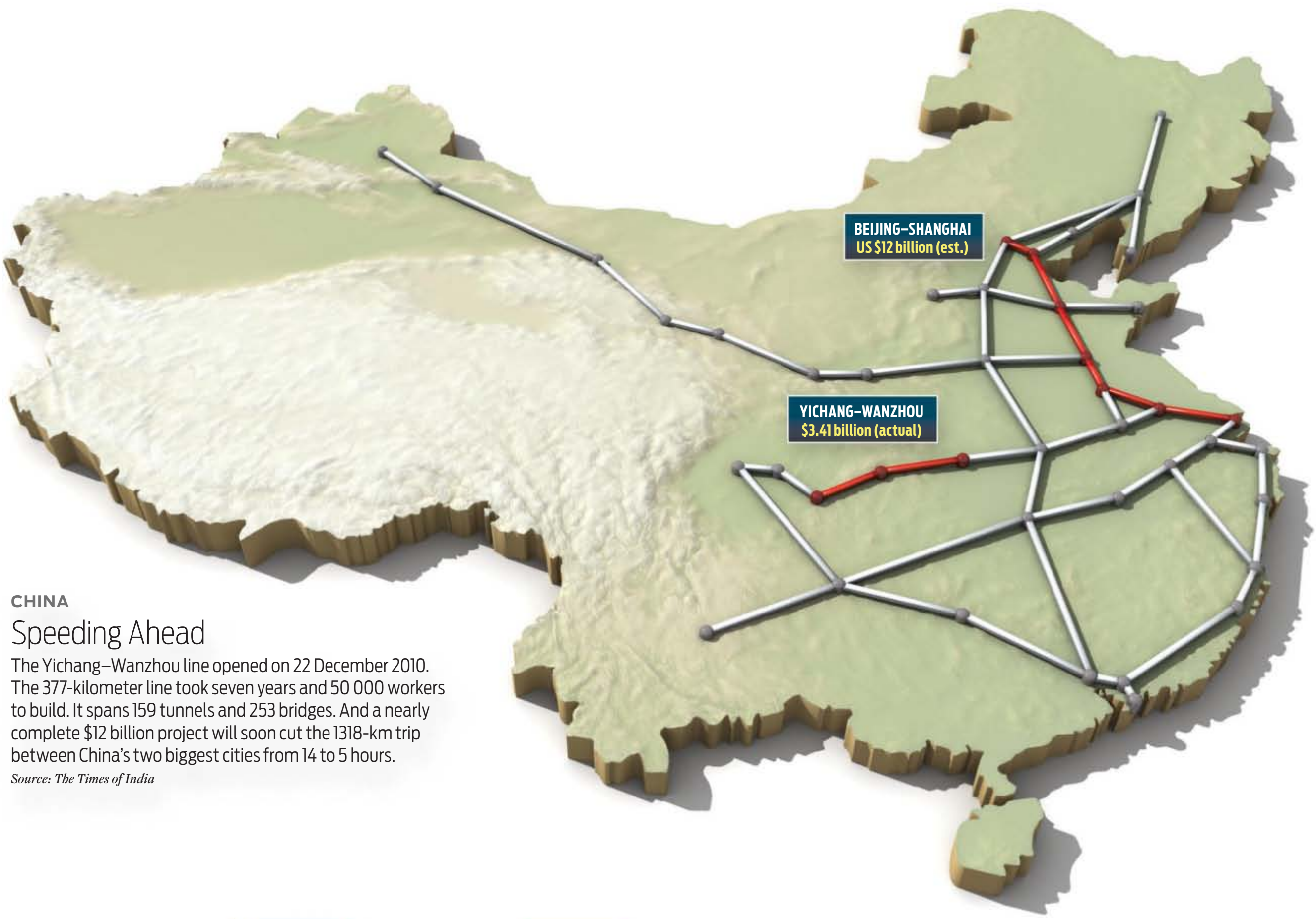

CHINA

Speeding Ahead

The Yichang–Wanzhou line opened on 22 December 2010. The 377-kilometer line took seven years and 50 000 workers to build. It spans 159 tunnels and 253 bridges. And a nearly complete $12 billion project will soon cut the 1318-km trip between China's two biggest cities from 14 to 5 hours.

Source: The Times of India

UNITED STATES

Getting Into Gear

US $8 billion in stimulus money will kick-start a nationwide program of high-speed rail service.

Sources: Whitehouse.gov; National Conference of State Legislatures; SilverRail Technologies; Office of the White House; ABC News

SPAIN

Europe's High-Speed Leader

The Madrid–Valencia line opened on 19 December 2010. The 438-km journey takes 90 minutes.

Source: AFP

High-Speed Rail Is in High Gear

IN 2009, high-speed rail garnered more than twice as much investment as air travel, a total of US $200 billion, $88 billion of which was in China, according to Aaron Gowell, CEO of SilverRail Technologies, a system integrator in Wakefield, Mass., that specializes in high-speed rail. Around the world, some 40 000 kilometers of high-speed rail track are under construction.

In Europe, where the length of high-speed rail is expected to quadruple in the next decade, Spain is the leader. A newly completed link between Madrid and Valencia gives the country 2056 km of high-speed rail. Another 3469 km are in the works.

The industry's taking off even in the United States, where a half century of highway subsidies has long sidelined rail development. Last year, as part of the so-called economic stimulus, the Obama administration awarded an initial $8 billion for high-speed passenger rail projects. Major links include Tampa–Orlando, Chicago–St. Louis, and Sacramento–San Francisco–Stockton.

Still, such development is dwarfed by growth in China, which is in the midst of a $500 billion, 20-year program to connect the entire country, from Harbin in the northeast to Hong Kong to Urumqi in the remote northwest. One seven-year project, which crossed the Yunnan–Guizhou Plateau, required 159 tunnels, 253 bridges, and $3.4 billion. High-speed rail is not for the faint of heart. —*Steven Cherry*

EMILY COOPER

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