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2014 Reflections on Innovation 2014

January

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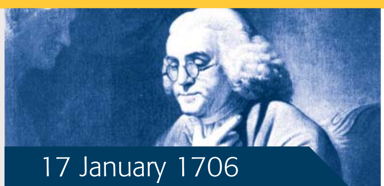

17 January 1706

One of the greatest early electrical scientists and engineers—in fact, one of the greatest inventors and thinkers of the Enlightenment—Benjamin Franklin was born in Boston, Massachusetts, U.S.A. He died on 17 April 1790 in Philadelphia, Pennsylvania, U.S.A.

February

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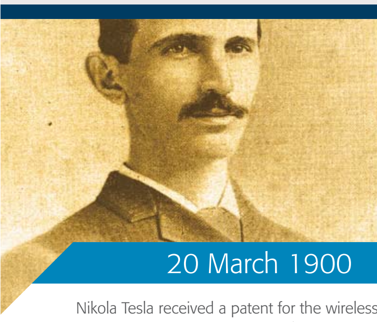
22 February 1857

Heinrich Rudolph Hertz, the physicist who demonstrated the existence of electromagnetic waves, was born in Hamburg, Germany. He died on 1 January 1894 in Bonn, Germany.



20 March 1900

Nikola Tesla received a patent for the wireless transmission of electric power.

March

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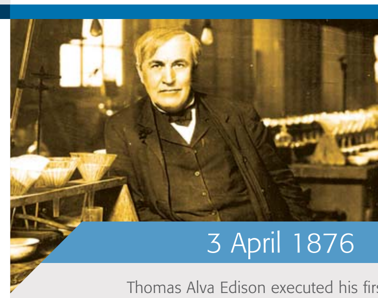

3 April 1876

Thomas Alva Edison executed his first patent applications from Menlo Park, New Jersey, U.S.A. on acoustic telegraphy.

April

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22 May 1973

Robert Metcalfe, research engineer at Xerox's Palo Alto Research Center, developed the idea of a local-area network that became Ethernet.

June

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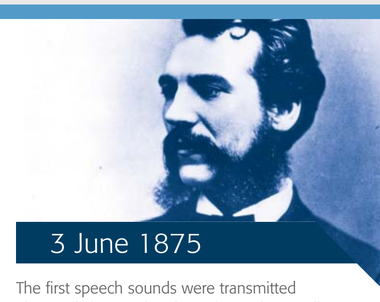
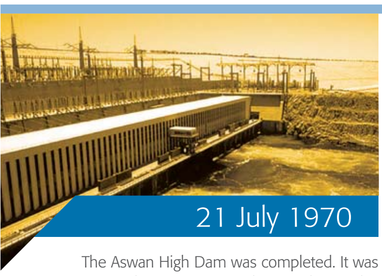


3 June 1875

The first speech sounds were transmitted electrically by wire by Alexander Graham Bell and Thomas A. Watson.



21 July 1970

The Aswan High Dam was completed. It was inaugurated in January 1971 by President Sadat. The dam produces hydroelectricity and supplies 50% of Egypt's power needs.

JULY

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5 August 1858

The first transatlantic telegraph cable was completed, establishing communication between Europe and North America. The cable was more than 1,950 miles long and in most places some lay two miles below the surface.

AUGUST

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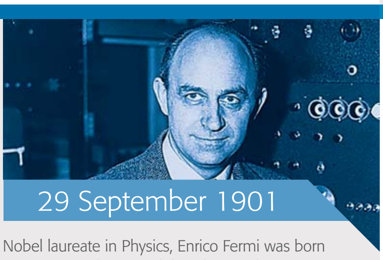

29 September 1901

Nobel laureate in Physics, Enrico Fermi was born in Rome. He discovered that slowing down neutrons increased their effectiveness in triggering nuclear fission. His discovery was of great importance for nuclear reactors to generate electricity.

OCTOBER

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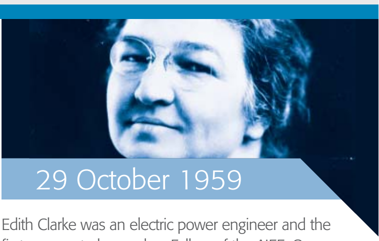

29 October 1959

Edith Clarke was an electric power engineer and the first woman to be made a Fellow of the AIEE. Over the course of her career, Clarke was an employee of AT&T in New York City, an instructor at the Constantinple Women's College, a researcher at General Electric, and an educator at the University of Texas.

24 November 1969

Apollo XII, the second manned mission to the surface of the moon, successfully returned to Earth.

NOVEMBER

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27 December 1924

Bell Telephone Laboratories, commonly known as Bell Labs, was organized. Bell Telephone Company also announced that its new research wing would begin operations on 1 January 1925.

DECEMBER

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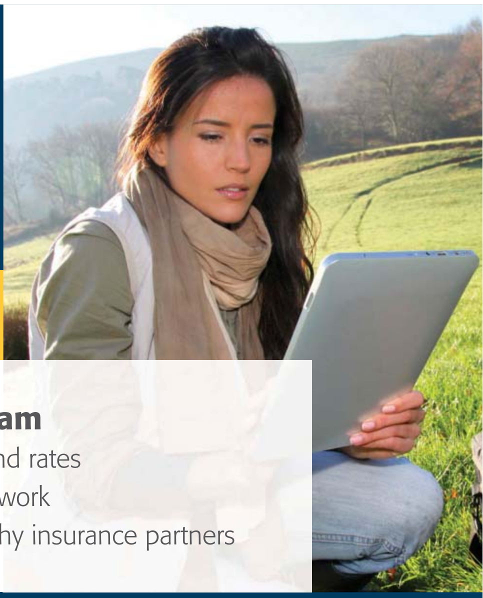

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For this new era of warfare, we need to set humanitarian limits on cyberattacks.

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The physicist envisioned armies of industrial and household robots doing the work of humans. He almost got it right.

By David C. Brock

On the Cover **Illustration for *IEEE Spectrum* by Eddie Guy**

PHOTOGRAPH BY Adam Voorhes

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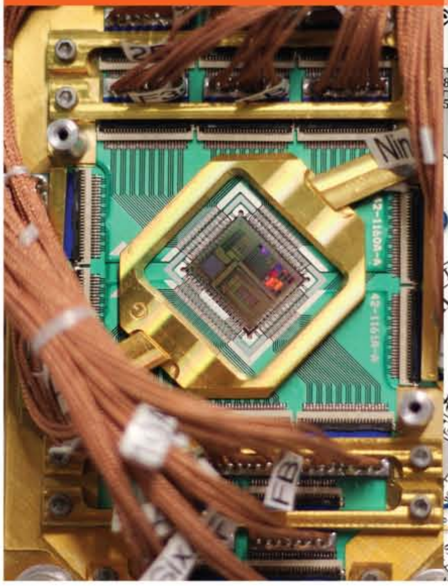


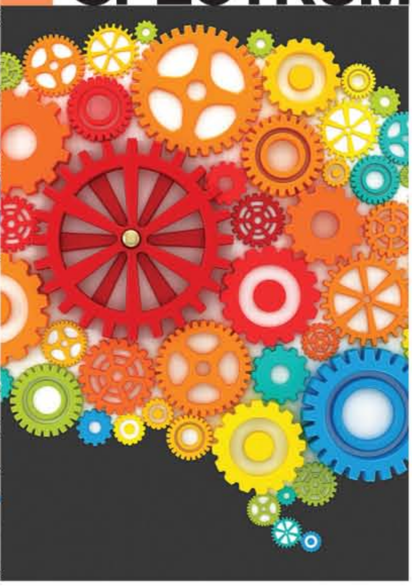

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Online Spectrum.ieee.org

Patent Power 2013
Which companies and organizations have the best patent portfolios? Our annual survey—conducted by 1790 Analytics—measures the quality and quantity of U.S. patents. It shows that consumer-facing companies such as Google and Facebook continue to rise through the rankings.

ADDITIONAL RESOURCES

Tech Insider / Webinars

Available at spectrum.ieee.org/webinar

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- Introduction to Antenna Simulation With COMSOL—5 December
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The Institute

Available 6 December at theinstitute.ieee.org

EVERYDAY NANOTECHNOLOGY This special issue of *The Institute* focuses on several new applications of nanotechnology. But you might be surprised to learn that nanotech is found in many products you're probably using already.

A RISING STAR Alexandra Boltasseva was named one of *MIT Technology Review*'s top innovators under 35, and her work in nanophotonics—light manipulation at the nanoscale level—earned her two awards this year.

ASK THE EXPERT K. Eric Drexler, IEEE member and author of *Radical Abundance: How a Revolution in Nanotechnology Will Change Civilization*, will be answering readers' questions about nanotechnology at *The Institute* online.

FROM LEFT: D-WAVE SYSTEMS; HOPTROFF; BARIS SIMSEK/GETTY IMAGES

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BACK STORY_

Connecting the Documents

AMONG HIGH-TECH LUMINARIES, few shine brighter than William Shockley–with good reason. He invented the junction transistor, shared the Nobel Prize in physics, and founded the first silicon electronics laboratory in what would become Silicon Valley. Late in life, he espoused some execrable ideas about race and intelligence. His exploits and his views have been minutely chronicled in books, articles, and documentaries.

In such a well-documented life, can there be any surprises? There sure can. After opening up a folder in the Shockley archives at Stanford University, David C. Brock [above] was stunned to discover an unexplored period of Shockley's long career, during which the physicist fervently believed in the feasibility of launching a robotics revolution. "I thought, Shockley's doing stuff with robots in 1951?" Brock recalls. "I nearly fell out of my seat."

Around the same time, Brock, a senior research fellow at the Chemical Heritage Foundation, gained access to some new archival material about the chemist-entrepreneur Arnold O. Beckman–files that had been discovered in the attic of Beckman's company headquarters. "The papers were supposed to have been destroyed, but somebody recognized they were Dr. Beckman's very own files, so instead they shoved them into the attic," Brock explains.

The files revealed how Shockley and Beckman first met and bonded over their mutual fascination with automation; how Shockley tried, unsuccessfully, to convince Beckman to use Shockley's patent on a robot eye; and how the two eventually agreed to form a transistor lab together.

"In the historical literature, there were many versions of how this connection between the two happened," Brock says. "Some said Shockley just got money from Beckman; some said Shockley approached Beckman to join a board of a new company. But in all of the accounts, there seemed to be a little bit of hand waving." To read Brock's full, no-hands-waving account, see "Shockley's Robot Dream," in this issue. ■

CITING ARTICLES IN IEEE SPECTRUM *IEEE Spectrum* publishes an international and a North American edition, as indicated at the bottom of each page. 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, Dataflow is in *IEEE Spectrum*, Vol. 50, no. 12 (INT), December 2013, p. 56, or in *IEEE Spectrum*, Vol. 50, no. 12 (NA), December 2013, p. 76.

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PHOTOGRAPH BY **Chattman Photography**

CONTRIBUTORS_

Jeremy Hsu

Brooklyn, N.Y.–based reporter Hsu knew the time was right for a story about the Canadian quantum-computer company D-Wave Systems and its controversial claims [News, p. 7]. "There are finally independent studies that go at these big questions that have been hanging over this company from the start," he says. "It was time to check in with the quantum-computing community to see if their attitude had changed." The answer? It's complicated.

Jesse Lefkowitz

When asked to illustrate this month's Technically Speaking ["Clamorous Computing," p. 24], Lefkowitz considered the idea of intrusive technology in his own life. Just thinking about the effects of being constantly plugged in "was very stressful." Inspired to reduce such tech distractions, he says, "I decided I wasn't going to check Facebook while I was working on this project." To further clear his mind, Lefkowitz also plays ultimate Frisbee and hikes near his home in Berkeley, Calif.

Karl Rauscher

An electrical engineer by training, Rauscher heads the Worldwide Cybersecurity Initiative at the EastWest Institute, a think tank that enables back-channel diplomacy between institutions and governments that may not normally cooperate. If nations can be brought together to discuss placing limits on cyberattacks, as Rauscher proposes in "Writing the Rules of Cyberwar" [p. 26], he wants to be sure engineers are involved in the conversation. "The world can't solve this problem without EEs," he says.

Rodney S. Tucker

Tucker, who wrote "Australia's (Less Super) Superhighway" [p. 44], is a professor of electrical engineering at the University of Melbourne and an IEEE Fellow. In 2008, the Australian government appointed him to an expert panel that recommended building a nationwide all-fiber broadband network. Although this ambitious project is now in danger of being downscaled, Tucker considers his work on the panel "one of the most significant contributions of my engineering career."

Adam Voorhes

"We do some pretty crazy things," says Voorhes of his photography studio in Austin, Texas. He describes his work as "conceptually driven still life." Collaborating with a stylist (who is also his wife) and an assistant, he distilled Australia's stalled broadband program into a single image [p. 44]. To do that, the group made a wire outline of Australia, fed monofilament strands through it until they fanned out into the desired shape, and then lit the contraption from below.

PHOTO-ILLUSTRATIONS BY **Gluekit**

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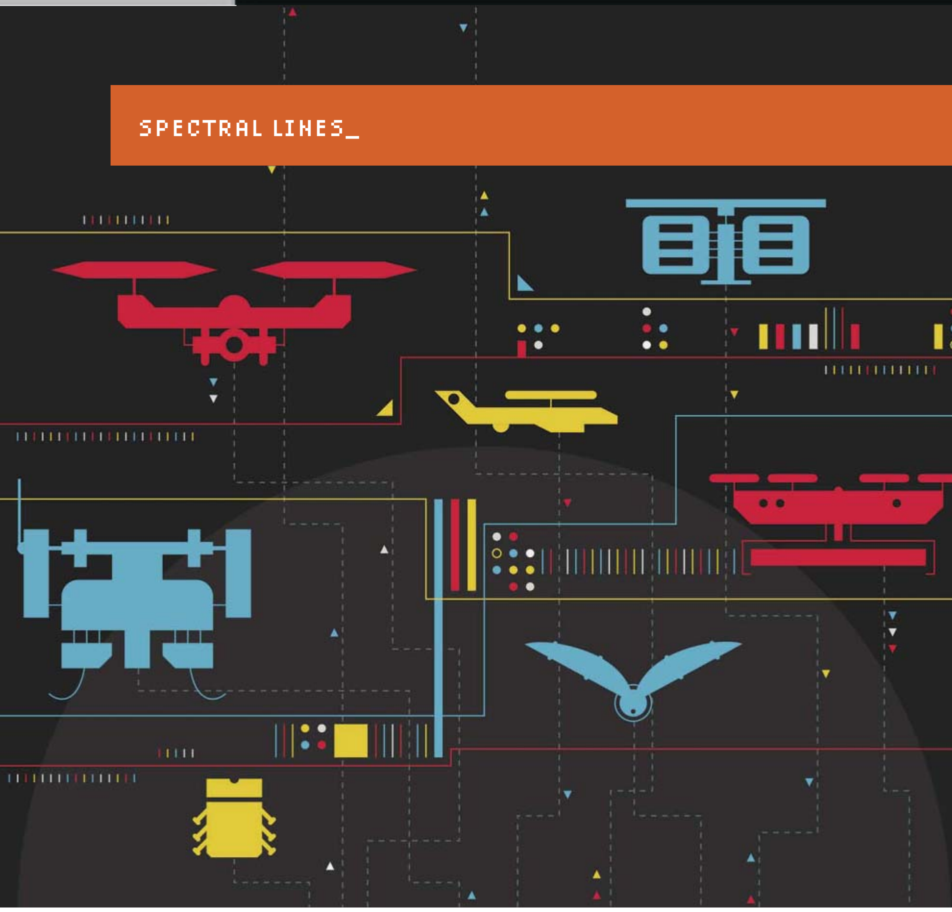


Gasping for Airspace

Sensible regulation of small drones would foster innovation and protect privacy

It's no secret that the United States may be losing its edge in civilian aviation. Nowhere is this more apparent than with small unmanned aircraft, those tiny flying robots that promise to transform agriculture, forestry, pipeline monitoring, filmmaking, and more. While many other countries are racing to develop and use such drones, U.S. innovators remain more or less stuck on the starting line, mired in federal indecision and red tape. At the recent Drones and Aerial Robotics Conference, at New York University, one speaker imagined what would happen if the Wright brothers were to face such restrictions today: Moments before takeoff, a black Chevy Suburban would pull up, federal agents would jump out, and they would halt the ill-conceived experiment for safety reasons.

While such intervention seems oddly reasonable today, government safety mandates are now being extended to astonishingly small scales. In 2007, the Federal Aviation Administration declared that small flying contraptions, even those the size of your hand, are considered “aircraft” and therefore require a Certificate of Authorization if they are flown outside for anything other than recreation—even if they hover just an inch above the grass. One high-level policymaker conceded that tossing a paper airplane for research or educational purposes would technically require FAA approval.

So it's no surprise that many other countries, including Brazil, Canada, China, France, Israel, Japan, New Zealand, and Switzerland, are moving ahead of the United States in civilian drone use and development, the most rapidly growing sector of civil aviation. These nations are capitalizing on the emergence of new technologies, building patent portfolios, and creating high-tech jobs that a decade ago would have been located in the United States.

What is surprising, though, is that these regulatory restrictions are also exacerbating privacy concerns. This is because when federal aviation regulations limit what people can do in their backyards and neighborhoods, it implies that citizens are now living *within*, rather than below, public navigable airspace. This becomes a radical proposition when the aircraft at issue are the size of Frisbees.

If all this sounds far-fetched, consider that the FAA already allows hobbyists to fly camera-laden model airplanes low over other people's property without their knowledge. The resulting video recordings are increasingly posted on the Internet, where they are public, permanent, and searchable. What happens when paparazzi, private investigators, and even companies like Google get in on the action? You don't have to be a privacy activist to find the prospects unsettling.

Fortunately, there's a straightforward solution: Keep public navigable airspace exactly where it's been for nearly a century now—hundreds of feet above our heads. This would leave landowners and local communities firmly in control of their backyards, neighborhoods, farms, and towns. Such a policy is also consistent with the landmark Supreme Court case *United States v. Causby*, which found that landowners “must have exclusive control of the immediate reaches of the enveloping atmosphere.”

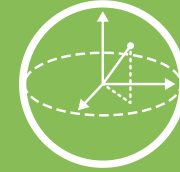
This framework would ensure a far more human world, one where small drones are just tiny flying contraptions, not FAA-certified aircraft with the public right of transit over our tulips. These fascinating new tools could then be used where landowners and local laws allow, safely below navigable airspace and out of the way of full-size aircraft. This solution would give innovators some air to breathe and put the United States back in the game as the world begins the second century of civilian aviation. —PAUL VOSS

Paul Voss is a mechanical engineer and atmospheric scientist in the Picker Engineering Program at Smith College, in Northampton, Mass.

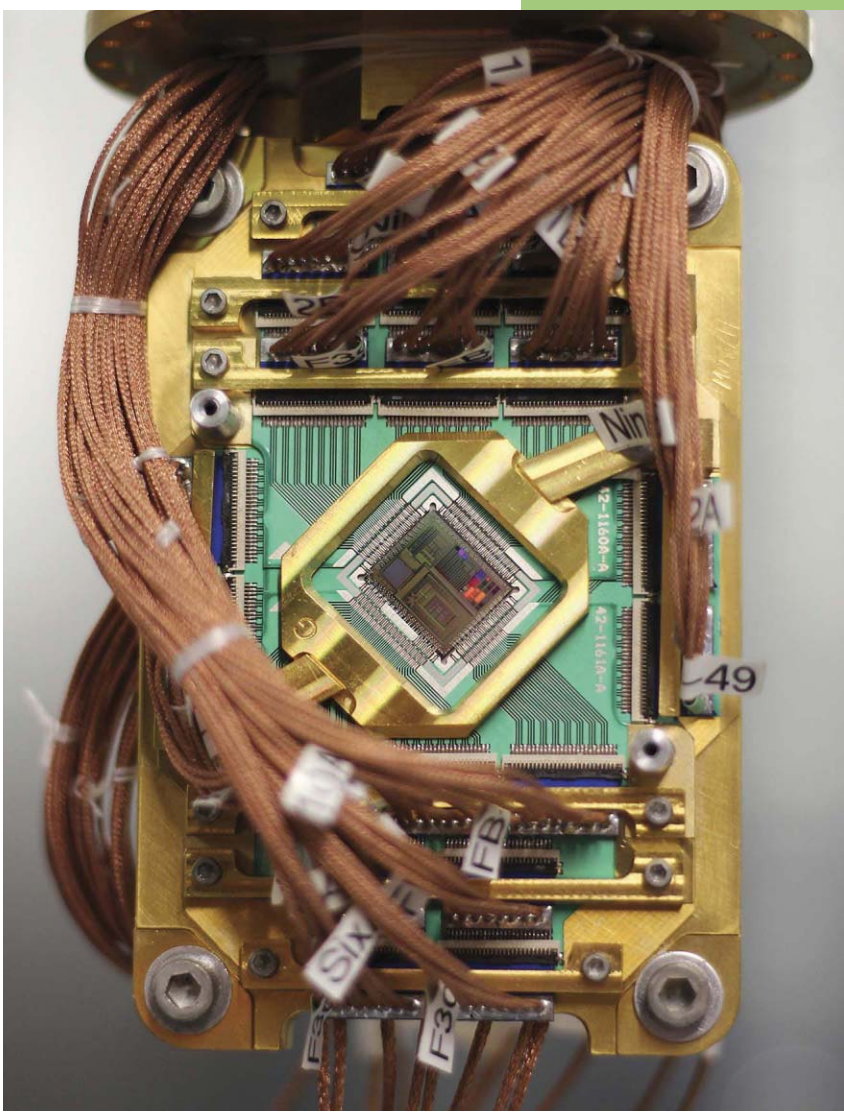
Correction: Because of an editing error, the article “Colorado River Hydropower Faces a Dry Future” [October 2013] misstated the location of Lake Mead. It is on the border of Arizona, not Colorado.

ILLUSTRATION BY Eric Frommelt

NEWS



512: THE NUMBER OF QUANTUM BITS IN THE D-WAVE TWO



D-WAVE SYSTEMS

D-WAVE'S YEAR OF COMPUTING DANGEROUSLY

After a year of outside investigation, questions remain about a controversial quantum computer

When in 1935 physicist Erwin Schrödinger proposed his thought experiment involving a cat that could be both dead and alive, he could have been talking about D-Wave Systems. The Canadian start-up is the maker of what it claims is the world's first commercial-scale quantum computer. But exactly what its computer does and how well it does it remain as frustratingly unknown as the health of Schrödinger's poor puss. D-Wave has succeeded in attracting big-name customers such as Google and Lockheed Martin Corp. But many scientists still doubt the long-term viability of D-Wave's technology, which has defied scientific understanding of quantum computing from the start.

D-Wave has spent the last year trying to solidify its claims and convince the doubters. "We have the world's first programmable quantum computer, and we have third-party results to prove it computes," says Vern Brownell, CEO of D-Wave.

But some leading experts remain skeptical about whether the D-Wave computer architecture really does quantum computation and whether its particular method gives faster

SOUL OF THE MACHINE: What's going on inside the D-Wave Two is still a matter of debate.

solutions to difficult problems than classical computing can. Unlike ordinary computing bits that exist as either a 1 or a 0, the quantum physics rule known as superposition allows quantum bits (qubits) to exist as both 1 and 0 at the same time. That means quantum computing could effectively perform a huge number of calculations in parallel, allowing it to solve problems in machine learning or figure out financial trading strategies much faster than classical computing could. With that goal in mind, D-Wave has built specialized quantum-computing machines of up to 512 qubits, the latest being a D-Wave Two computer purchased by Google for installation at NASA's Ames Research Center in Moffett Field, Calif.

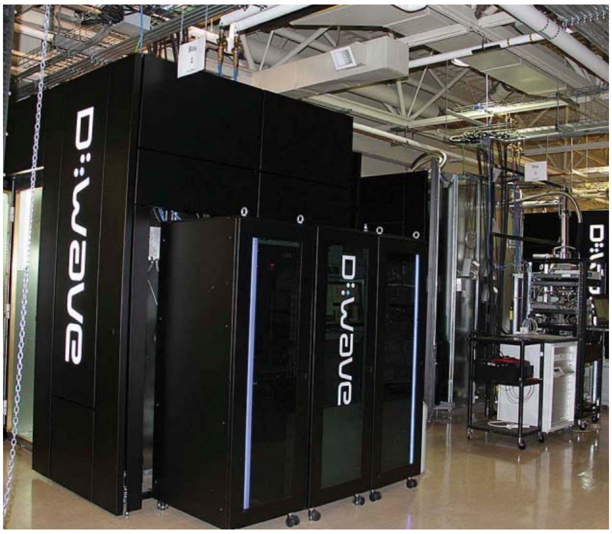
D-Wave has gained some support from independent scientific studies that show its machines use both superposition and entanglement. The latter phenomenon allows several qubits to share the same quantum state, connecting them even across great distances.

But the company has remained mired in controversy by ignoring the problem of decoherence–the loss of a qubit's quantum state, which causes errors in quantum computing. "They conjecture you don't need much coherence to get good performance," says John Martinis, a professor of physics at the University of California, Santa Barbara. "All the rest of the scientific community thinks you need to start with coherence in the qubits and then scale up."

Most academic labs have painstakingly built quantum-computing systems–based on a traditional logic-gate model–with just a few qubits at a time in order to focus on improving coherence. But D-Wave ditched the logic-gate model in favor of a different method called quantum annealing, also known as adiabatic quantum computing. Quantum annealing aims to solve optimization problems that resemble landscapes of peaks and valleys, with the lowest valley representing the optimum, or lowest-energy, answer.

Classical computing algorithms tackle optimization problems by acting like a bouncing ball that randomly jumps over nearby peaks to reach the lower valleys–a process that can end up with the ball getting trapped when the peaks are too high.

Quantum annealing takes a different and much stranger approach. The quantum property of superposition essentially lets the ball be everywhere at once at the start of the operation. The ball then concentrates



COLD AND QUANTUM: The D-Wave Two quantum computer [smaller black box] operates within a large refrigeration unit.

D-WAVE SYSTEMS

in the lower valleys, and finally it can aim for the lowest valleys by tunneling through barriers to reach them.

That means D-Wave's machines should perform best when their quantum-annealing system has to tunnel only through hilly landscapes with thin barriers, rather than those with thick barriers, Martinis says.

Independent studies have found suggestive, though not conclusive, evidence that D-Wave machines do perform quantum annealing. One such study–with Martinis among the coauthors–appeared in the arXiv e-print service this past April. Another study by a University of Southern California team appeared in June in *Nature Communications*.

But the research also shows that D-Wave's machines still have yet to outperform the best classical computing algorithms–even on problems ideally suited for quantum annealing.

"At this point we don't yet have evidence of speedup compared to the best possible classical alternatives," says Daniel Lidar, scientific director of the Lockheed Martin Quantum Computing Center at USC, in Los Angeles. (The USC center houses a D-Wave machine owned by Lockheed Martin.)

What's more, D-Wave's machines have not yet demonstrated that they can perform significantly better than classical computing algorithms as problems become bigger. Lidar says D-Wave's machines might eventually reach that point–as long as D-Wave takes the problem of decoherence and error correction more seriously.

The growing number of independent researchers studying D-Wave's machines marks a change from past years when most interactions consisted of verbal mudslinging between D-Wave and its critics. But there's still some mud flying about, as seen in the debate over a May 2013 paper that detailed the performance tests used by Google in deciding to buy the latest D-Wave computer.

Catherine McGeoch, a computer scientist at Amherst College, in Massachusetts, was hired as a consultant by D-Wave to help set up performance tests on the 512-qubit machine for an unknown client in September 2012. That client later turned out to be a consortium of Google, NASA, and the Universities Space Research Association.

Media reports focused on the fact that D-Wave's machine had performed 3600 times as fast as commercial software by IBM. But such reporting overlooked McGeoch's own warnings that the tests had shown only how D-Wave's special-purpose machine could beat general-purpose software. The tests had not pitted D-Wave's machines against the best specialized classical computing algorithms.

"I tried to point out the impermanency of that [3600x] number in the paper, and I tried to mention it to every reporter that contacted me, but apparently not forcefully enough," McGeoch says.

Indeed, new classical computing algorithms later beat the D-Wave machine's performance on the same benchmark tests, bolstering critics' arguments.

"We're talking about solving the one problem that the D-Wave machine is optimized for solving, and even for that problem, a laptop can do it faster if you run the right algorithm on it," says Scott Aaronson, a theoretical computer scientist at MIT.

Aaronson worries that overblown expectations surrounding D-Wave's machines could fatally damage the reputation of quantum computing if the company fails. Still, he and other researchers say D-Wave deserves praise for the engineering it has done.

The debate continues to evolve as more independent researchers study D-Wave's machines. Lockheed Martin has been particularly generous in making its machine available to researchers, says Matthias Troyer, a computational physicist at ETH Zurich. (Troyer presented preliminary results at the 2013 Microsoft Research Faculty Summit suggesting that D-Wave's 512-qubit machine still falls short of the best classical computing algorithms.)

Google's coalition also plans to let academic researchers use its D-Wave machine.

"The change we have seen in the past years is that by having access to the machines that Lockheed Martin leased from D-Wave, we can engage with the scientists and engineers at D-Wave on a scientific level," Troyer says.

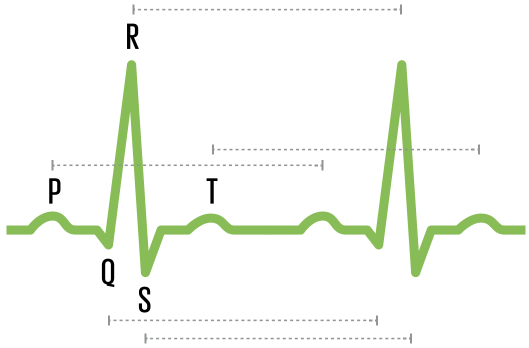
—JEREMY HSU

YOU ARE YOUR HEARTBEAT

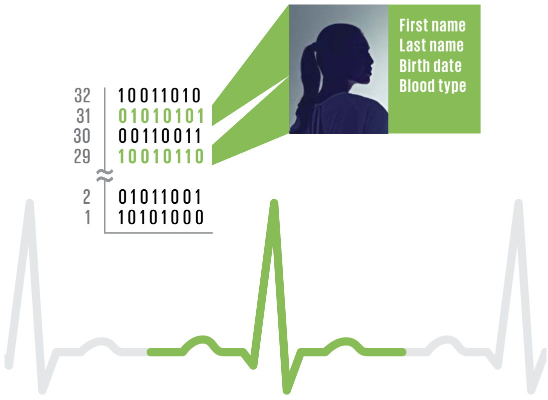
Electrocardiograms can reveal or conceal sensitive information

Our heartbeats keep us going, but they also say a lot about who we are. Different groups of researchers are taking advantage of the unique characteristics in electrocardiogram (EKG) readings to identify and authenticate individuals for things like online security and to protect patient confidentiality in health-care settings. EKG research into both biometric and steganographic techniques deals with patient identity, but while the former uses EKG results as an identifier, the latter uses the data to hide personal information. An EKG is useful in steganography because it generates a large quantity of data in which to hide other data. For biometrics, the data describe physical characteristics of the heart, including electrical activity and positions of the chambers, which could be unique to individuals. So two different paths to protecting identity use the same data in very different ways.

—LILY HAY NEWMAN



BIOMETRICS Investigations into the biometric identifying properties of EKG data have been going on for more than a decade. The peaks and valleys [P,Q,R,S, and T in the diagram at left] on an EKG readout represent the different phases of a heartbeat, and with the help of some processing, they can act as a physiological fingerprint. For example, when measuring the time between different events in the heartbeat, engineers at the JIS College of Engineering in Kolkata, India, were recently able to generate an 8-bit identifier, or "BioHash," for a given individual's EKG. An EKG could then be used in a process, similar to that of fingerprint scanning, that verifies an individual's identity by comparing new scans with the original ones.



STEGANOGRAPHY EKGs are often used as remote monitoring tools for homebound patients or those with chronic diseases. But when the test results are sent to doctors via the Internet, there's a risk that the data could wind up in the wrong hands. So engineers at RMIT University in Melbourne, Australia, came up with the idea of hiding identifiers like names and government ID numbers in the EKG readings themselves.

The process of hiding data inside a larger digital file is called steganography. The RMIT technique allows the researchers to break down an EKG into 32 sub-bands, identify those that do not contain data meaningful for diagnosis, remove the meaningless data, and insert encrypted patient information in its place.

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IT'S A GAS: This GE engine runs on biogas produced at the Beijing Deqingyuan Chicken Farm.

GE

NATURAL GAS SETS OFF A DISTRIBUTED-ENERGY BOOM

Fuel cells, engines, and hybrids of both get popular as gas prices fall

Rooftop solar has long been the poster child of distributed energy, but experts say the boom in the natural gas supply and memories of large-scale outages are also playing a big role in moving electricity generation out of the hands of big utilities.

Different gas-fueled technologies–fuel cells, microturbines, reciprocating engines, and turbines–are now competing for a spot in the basements of businesses. "People are genuinely waking up to their options," says Kerry-Ann Adamson, research director at Navigant Research. "Distributed-generation technology can be better than the current option of centralized power on the grid."

Depending on local electricity prices and government incentives, natural gas-powered distributed energy can be less expensive than grid power over the lifetime of the equipment. This is most often true if it's a combined heat and power unit–also called a cogeneration unit–in which the heat from electricity generation is captured as hot water or steam. There can be environmental benefits as well: Many of these technologies can run on gas from landfills or biomass digesters. When both heat and electricity are used, system efficiency can top 80 percent.

No single technology for natural-gas distributed generation has emerged as a clear winner. The engineering challenge is really doing the financial analysis, taking into account government incentives, and pairing the technology with the best application, says Robert Rose, vice president of specialty services at the construction and engineering firm A/Z Corp. Refrigerator-size microturbines, for instance, can vary output quickly, which is useful for shaving peak load to lower electricity costs. Fuel cells, meanwhile, are better for base-load power and have good electrical efficiency, but they cost more per kilowatt than engines or turbines.

Already a longtime maker of gas turbines for power plants, General Electric is betting big on natural gas for distributed generation. Its global research arm is developing a machine that will combine a solid-oxide fuel cell with one of its existing natural gas-fired engines. The fuel cell generates electricity from reformed natural gas–gas that's treated with steam, a by-product of the fuel cell, and heat to make carbon monoxide and hydrogen. Then, in a twist on conventional fuel cells, GE uses a variety of techniques–it won't say exactly which–to treat the residual gases from the fuel cell and make them suitable for burning in an internal combustion engine to generate electricity again. The combination allows the device to reach 70 percent electrical efficiency, according to GE.

GE is also developing small-scale liquefied-natural-gas and compressed-natural-gas fueling stations, which could connect to existing pipelines and fuel remote industrial sites or microgrids in emerging markets, says Michael Farina, the fuels market intelligence leader at GE. They could be supplied from a variety of regional sources, such as shale rock, coalbed methane, and biogas. "You can start to see a picture where there could be a lot more supply and infrastructure available than people think," he says.

eBay has taken distributed generation to the extreme. As its primary power source, the company's newest data center, in Utah, uses 4.8 megawatts of an available 6 MW from a natural gas-powered fuel-cell system made by Bloom Energy. The center uses the main grid only as backup. The design reduced the data center's capital cost, because there was no need for backup diesel generators or uninterruptible power supplies. The operating costs are similar to those of grid power with on-site backup, says Dean Nelson, eBay's vice president of global foundation services. "The fuel cell design...has fewer failure points. When you lose a part in a fuel cell, you just lose the capacity; you don't fault the whole system," he says. The operation will also lower eBay's carbon emissions by 49 percent compared with those of the local coal-powered grid, according to an analysis from the University of Illinois. eBay's design is already being considered by other big data-center operators, Nelson says.

Natural gas-powered generation has another benefit that's driving adoption, especially in the United States. Because gas pipelines are buried, they work when the electricity grid is knocked out by storms. Last year, Superstorm Sandy in the U.S. Northeast, which cut power for more than 8 million households, was a shining moment for engines, turbines, and fuel cells, which partially powered university campuses, government agencies, and businesses during the storm's aftermath.

Since then, policymakers and big electricity users have been looking at distributed energy as an insurance policy. "Initially, it was all driven by economics. Now, we're seeing [that] the aspect of resilience has [had] a more objective influence on decisions," says Rose. Solar or wind can't be relied on like a generator or fuel cell, and adding energy storage to provide power on demand is expensive.

> Different gas-fueled technologies—fuel cells, microturbines, reciprocating engines, and turbines—are now competing for a spot in the basements of businesses

But natural gas-fueled on-site generation has a number of hurdles, too. The payback can be less compelling if reliability or potential environmental benefits aren't considered, and retrofitting existing buildings can be tricky. Many utilities are wary of distributed energy in general because it upends their traditional business model. Still, some experts say, creating pockets of distributed power can make the grid more reliable overall.
MARTIN LAMONICA

A NEW RECORD FOR TERAHERTZ TRANSMISSION

Engineers achieve amazing data rates in a once-inaccessible band

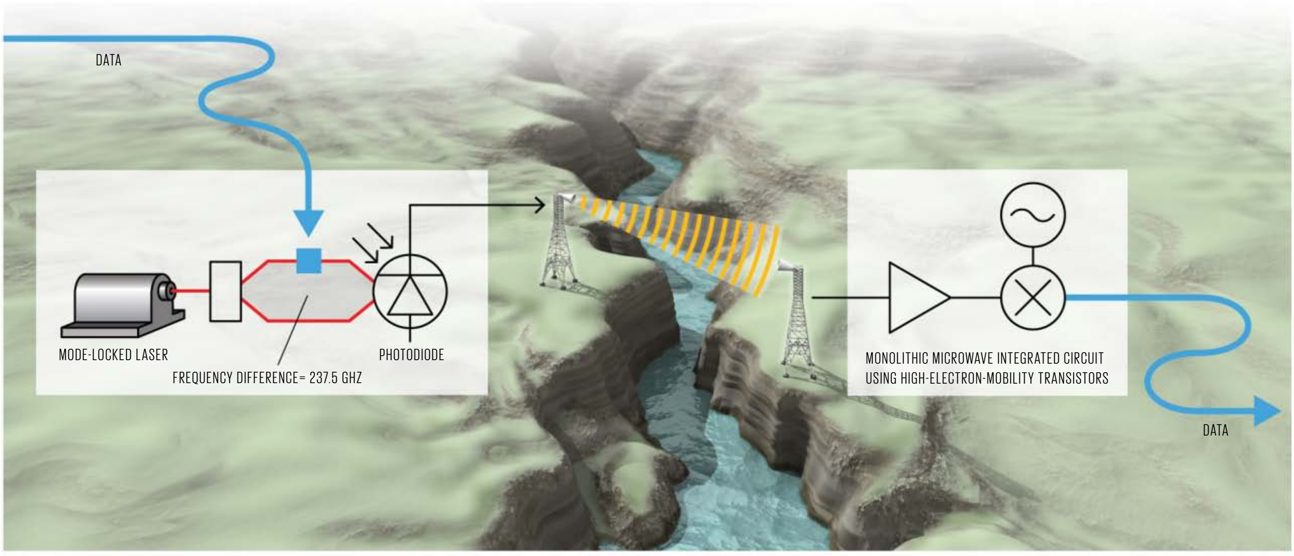
The problem with the radio spectrum between 3 and 3000 megahertz is that it's crowded. Television, radio, mobile phones, Bluetooth, GPS, two-way communication devices, and Wi-Fi all operate in this high- to ultrahigh-frequency range. So with nowhere to go but up, researchers have been working for decades to utilize the 3- to 3000-gigahertz span. In October, a team reported a hopeful sign—a record 100-gigabit-per-second wireless data transmission.

Scientists in Germany, at the Karlsruhe Institute of Technology (KIT), the Fraunhofer Institute for Applied Solid State Physics, and the University of Stuttgart, created a wireless connection between a transmitter and a receiver that were 20 meters apart at a frequency of 237.5 GHz. This frequency is in the millimeter-wave portion of the spectrum and tantalizingly close to the terahertz region (usually defined as starting at 300 GHz). The terahertz region has a lot of potential because its radiation is nonionizing and yet can penetrate clothing, making possible things like advanced bomb detection and body screening.

Terahertz and subterahertz frequencies have also been investigated for decades as a high-speed data-transfer solution, especially for rural or remote locations where extending the fiber-optic network would be difficult and costly. In the study, published in October in *Nature Photonics*, the data transfer is 10 times as fast as the 1-Gb/s speeds promised by Google Fiber and other gigabit initiatives being tested in certain cities.

"For us, the most exciting thing was to do wireless communication at this carrier frequency, at this high data rate, where nobody else could do it before," says Swen König, a photonics research engineer at KIT. "It's only the beginning of telecommunications at this frequency."

To achieve such high data rates the researchers put together an experimental system that combined



BRIDGING A GAP: Two components from the beam of a mode-locked laser shine on a photodiode to produce near-terahertz radiation. A monolithic microwave IC receives the signal and extracts the data.

cutting-edge electronics and photonics. They elected to add photonic elements to the transmitter setup instead of just using electronics, because the photonics enabled a larger bandwidth and a larger dynamic range. The downside, however, was that the photonic scheme lowered the transmitter's output power.

The team used a device called a photon mixer (borrowed from the Japanese company NTT-NEL), which combines and directs two lasers of different frequencies onto a photodiode. One laser is modulated to carry data; the other is not. Shining the lasers on the photodiode produces an electrical signal with a frequency that equals that of the difference between the lasers–237.5 GHz. That signal is then radiated by a horn-shaped antenna.

On the receiver end, the team used a custom-built integrated circuit made up of high-electron-mobility transistors, compound semiconductor devices that can operate at millimeter-wave frequencies. At just a few square millimeters, the chip is a big step toward the ability to incorporate terahertz receiving technology in smartphones and tablets. The IC amplified the incoming radiation and mixed it with another frequency to extract the transmitted data.

John Federici, a professor of physics at New Jersey Institute of Technology who studies terahertz technology, is impressed by the research. He says the 20-meter transmission distance is somewhat limiting, but he notes that it would be adequate for many schemes that technologists have dreamed up for terahertz data transfers. "Some people talk about a data kiosk that's streaming high data rates to mobile users," he says. "They walk up to the data kiosk, they download their videos or whatever at very high data rates, and they move away." Federici cautions against generalizing the idea too much, though, saying that terahertz and near-terahertz frequencies propagate unreliably in the atmosphere or through walls in homes.

One feature of subterahertz transmission that the German group find especially promising is that this type of radiation is less affected by local conditions like fog or rain when compared with free-space optical transmission, which uses lasers to carry data through the air. But Carter Armstrong, a vice president and terahertz expert at L-3 Communications, points out that the researchers did not actually test their design in these types of obstructed conditions. "They say that free-space terahertz transmission–in their case upper-millimeter-wave–is less affected by rain and fog," so they should "demonstrate it by operating the system," he says.

KIT's König agrees that applications in which a user has a clear line of sight between the transmitter and receiver are the most promising right now. But he also says the research team is confident that they can scale up the technology to transmit over a distance of several hundred meters. They already broke a long-range record in May for transmitting 40 gigabits per second over more than a kilometer at 240 GHz using a purely electronic system. The output power of the photodiode was the limiting factor in this recent experiment, but new research is under way aimed at adding an amplifier after the photodiode to boost the signal.

More broadly, development for many components of the experimental setup is continuing at the different institutions. "This was an interplay between so many different partners and technologies," König says. "The satisfaction was that all these concepts worked." –LILY HAY NEWMAN

ILLUSTRATION BY Emily Cooper

CHINA'S MOON MACHINE

The Chang'e-3 lander and rover should touch down this month

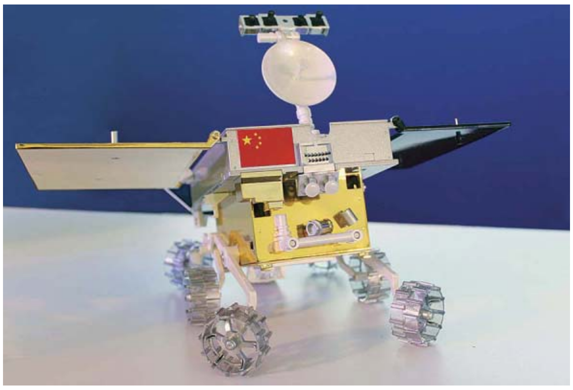
If all goes according to plan, the red flag of China will soon fly on the moon's surface. The Chang'e-3 mission is scheduled to launch in early December, and its lander should touch down on the lunar surface by the end of the year. Then a rover should roll off the lander's ramp and start making tracks in the regolith.

It's a complicated maneuver, and plenty could go wrong, experts say. However, if the mission is a success, it will be the first moon landing since the Russian Luna 24 mission in 1976.

China's Chang'e program, named after a moon goddess, has already had several resounding successes. In the first mission, the lunar orbiter Chang'e-1 arrived in orbit in 2007 to take 3-D images of the lunar surface; it operated until 2009 when it made a deliberate crash landing.

Next up, in 2010, was the orbiter Chang'e-2, which tested several key technologies necessary for this month's mission. Jiangchuan Huang of the Beijing Institute of Control Engineering presented the results of the 2010 mission at the International Astronautical Conference in Beijing this September. He says that one of those key technologies was the design of an Earth-to-moon flight trajectory that shaves eight days off the trip. The Chang'e-2 also demonstrated the braking maneuver that inserted the spacecraft into orbit at an altitude of 100 kilometers above the moon's surface, an action the Chang'e-3 spacecraft will duplicate before descending to the ground.

The second-generation craft also took high-resolution images of the presumed landing spot for this year's lander, a plain of basaltic lava in the northern hemisphere called Sinus Iridum. "Chang'e-2 made a solid foundation for China's follow-on lunar exploration program," Jiangchuan says.



MINI MOON ROVER: The rover portion of the Chang'e-3 mission to the moon sports some onboard intelligence.

GETTY IMAGES

Chang'e-3 will fly an Earth-to-moon trajectory that shaves eight days off the typical trip and puts it in orbit 100 kilometers above the surface

China's aerospace engineers had to master a number of new technologies for the Chang'e-3 mission, which were described in a recent report from the Beijing Institute of Spacecraft System Engineering. To land gently on the moon's surface, the spacecraft will use thrusters to slow its descent until it reaches an altitude of 100 meters. The lander will hover there as it scans the terrain for hazards using optical and laser imaging, and then an autonomous system will determine the safest landing spot and guide the craft down. When the Chang'e-3 is only 4 meters from the ground, its engine will shut off and it will drop, protected by a landing cushion.

Once the spacecraft is safely settled, the rover will start exploring the landscape. While it will primarily be under the control of operators back on Earth, the six-wheeled, 140-kilogram rover has its own onboard intelligence. It will use its software to construct a 3-D map of the terrain, recognize hazards and obstacles, and plan its path to a target.

Both the lander and the rover will do some science once they're established, but the Chinese space agency hasn't explained these scientific missions in detail. The lander is equipped with optical telescopes and an extreme ultraviolet camera for astronomical observations, while the rover carries infrared and X-ray spectrometers to study the chemical composition of rocks and soil.

Experts say the Chinese space agency has prepared carefully for the moon landing mission with extensive simulations, testing, and a tryout for the rover in a desert region of northwest China. "It's something the Chinese haven't done before, and they've gone to a lot of trouble to make sure it will work," says Brian Harvey, author of the recent book *China in Space*. "But landing on [the moon] is hard!"

While much of the current attention is focused on the landing, Harvey says the science experiments that the lander and rover will perform may turn out to be just as interesting. "They've given us a 90-day roving period, but I don't believe that at all," he says. "I think it will go a lot longer than that." He notes that NASA's Mars rovers also had a 90-day mission plan, and yet one of them is still rolling after nearly 10 years of operation.

The next stage of China's moon exploration program is a sample-return mission, scheduled for 2017. Many experts have speculated that a manned mission will follow in the 2020s, but the Chinese government hasn't announced its intention to send a taikonaut to take that one big step for China.
—ELIZA STRICKLAND

NEWS

PHOTOGRAPH BY Worldwide Aeros Corp.

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SILVER SURFER

THIS 81-METER-LONG airship, the Aeroscraft *Dragon Dream*, is actually just a scale model. Worldwide Aeros Corp., in Canoga Park, Calif., built it to show off a design that combines all the benefits of airplanes, helicopters, and traditional lighter-than-air aircraft. The *Dragon Dream*'s progeny will do vertical takeoffs from and landings on just about any flat surface, hover at full payload capacity while expending minimal energy, haul payloads exceeding 225 metric tons, and transport things, like wind turbine blades, that won't fit inside other workhorse aircraft. Though it gets most of its lift from helium, a set of downward-facing fans assist with takeoff and descent or keep the *Dragon Dream* hovering. Another set provides forward propulsion and, in conjunction with small airfoils, generates enough lift to supplement the craft's buoyancy while it's cruising.

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RESOURCES

GIFT GUIDE 2013

OUR ANNUAL ROUNDUP OF TECH GIFTS FOR ALL BUDGETS

RESOURCES_TOOLS

HOPTROFF

HOPTROFF No. 10

Modern time is maintained by atomic clocks that monitor the vibrations of cesium atoms. For most of us, we get this time secondhand, radioed from GPS satellites or relayed through digital networks. But a select few will be able to keep their own atomic time—losing only 1.5 seconds every thousand years—thanks to the Hoptroff No. 10, a pocket watch with a built-in cesium gas oven. The No. 10 is technically a marine chronometer, and with a sextant, it can be used to navigate across oceans. The London-based watchmaker Hoptroff will make only 12 of these timepieces. Customers will have to pass a security check before taking delivery next year, lest the precision timing technology be reverse engineered for things such as missile guidance. Pricing is on request but will be in the high five figures (U.S. dollars).

Richard Hoptroff, the company's founder and managing director, notes that there is little economic justification for the No. 10 but that once the key piece of technology became available—a miniaturized cesium oven made by Symmetricom—he had a "compulsion" to build it. —STEPHEN CASS

For a Q&A with Richard Hoptroff, read an extended version of this article online.

BROOKSTONE PERFECT DRINK

Continuing the long tradition of booze-related technological innovations, this US $70 scale, the Perfect Drink, is designed to aid the cocktail-impaired. Place an empty glass or cocktail shaker on the scale. An accompanying app on a tablet or smartphone lets you call up whatever cocktail you'd like to make from an extensive database. The app then tells you what ingredient to pour. The scale detects how much has been poured and tells you when to stop. If you add too much or too little, the system will try to compensate by automatically adjusting the amounts of subsequent ingredients. —S.C.

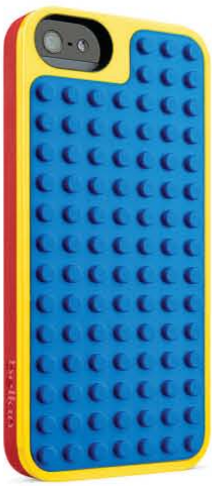
ATOMIC PRECISION: These cesium-oven-equipped movements [right] form the heart of the No. 10.

HOPTROFF; TOP RIGHT: BROOKSTONE

LEGO MINDSTORMS 3

After debuting at this year's Consumer Electronics Show in Las Vegas, the third revision of the Lego Mindstorms robotics kit finally went on sale in September. The $350 EV3 kit has new sensors, including a color detector, alongside a significantly upgraded "programmable brick" that serves as the heart of the system. As well as more computing power and memory capacity, the new brick can communicate wirelessly with a wider range of mobile devices—including, for the first time, iPads and iPhones. **–S.C.**

BELKIN LEGO BUILDER CASE



Build your phone into a Mindstorms robot, or create your own charging station with Belkin's Lego Builder Cases. The cases are available in two versions, one suitable for iPhones ($40) and one for iPods ($30), and they incorporate baseplates manufactured by Lego, so you can be sure of a perfect fit with your other blocks. **–S.C.**

LEFT: LEGO; RIGHT: BELKIN

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RETRO TV: LG 32LN630R

Once upon a time, TVs were styled as pieces of furniture in their own right, with care given to the look of cabinets and controls. But the flat-panel revolution created a trend toward making everything but the screen as invisible as possible. The LG 32LN630R bucks the trend with a retro design that allows channel selection and volume control via dials. For now, the $750 set is available only in South Korea. —S.C.

CYPHER LABS THEOREM 720 DAC

In the last year or so, a new category of consumer electronics has hit its stride. These products take a stream of digital audio data directly from an iPod, iPhone, or iPad and convert it into an audio signal. I'm particularly impressed by the Theorem 720 DAC by Cypher Labs, with its rugged build and astounding 18-hour battery life. The $900 Theorem 720 combines a headphone amplifier and a high-performance digital-to-analog converter (DAC) that bypasses the built-in DAC in your iOS device. Listening with one of these devices through a pair of great headphones results in a musical experience that is far superior to what you normally get from an iPod or iPhone (especially with audio encoded using a lossless file format). It can even rival the quality of a much more costly home audio system. —GLENN ZORPETTE

For an extended review of the Theorem 720, read this article online.

TOP: LGE; BOTTOM: CYPHER LABS

RESOURCES_TOOLS

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PARROT AR DRONE 2.0, POWER EDITION

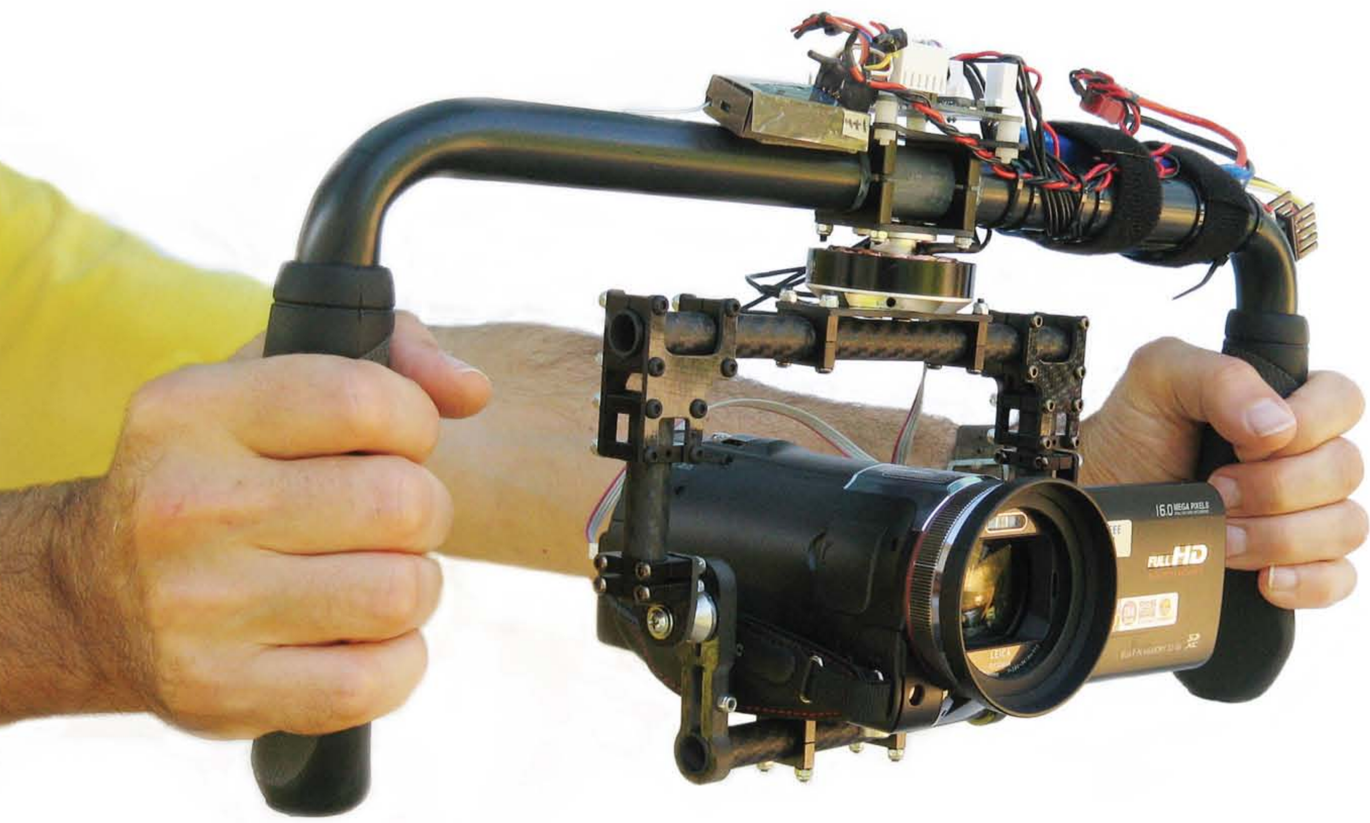
From Parrot comes the latest version of its popular AR Drone, the $370 Power Edition. In addition to the improved video camera and flight-control electronics of the 2.0 version, the Power Edition comes with two 1500-milliampere-hour lithium-ion polymer batteries. Between them, they provide up to 36 minutes of flight time, a substantive improvement over the 12 minutes or so possible with the single 1000-mA-hour battery that came with earlier versions. **–S.C.**

PARROT (3)

PARROT FLOWER POWER

Can't figure out why your office plants keep dying? Trying to grow the perfect rose? Stick the $60 Flower Power (also from Parrot) into the soil and you may get your answers. Two prongs measure capacitance and hence the amount of water present. Metal nubs above the prongs measure electrical resistance: Combining this with the capacitance gives an estimate of fertilizer levels. Above ground, light and temperature sensors round out the sensor package. The device takes measurements every 15 minutes, and it stores up to 80 days of data at time, which can be uploaded wirelessly to an iOS app. You can use an in-app database of thousands of plants to gauge if your particular shrub or flower is getting the right amount of, say, water or sunlight. **–S.C.**

READY, STEADY, SHOOT
AN ELECTRONICALLY STABILIZED VIDEO-CAMERA MOUNT FOR THE MASSES



IN THE 1970S, CAMERAMAN GARRETT BROWN WOWED THE MOVIE INDUSTRY BY INVENTING the Brown Stabilizer—soon renamed the Steadicam—a mechanical system for stabilizing motion-picture cameras. Brown's device relied on a clever arrangement of counterweights, and it permitted shots that would have been very difficult, if not impossible, to obtain previously, including many of the action scenes in 1976's *Marathon Man* and *Rocky*. ● Now the electronic counterpart to Brown's innovation is shaking up filmmaking—especially low-budget filmmaking. Driving much of the excitement is the US $15 000 MōVI M10, a camera-stabilization rig that Freefly Systems began shipping in August and that costs about a third as much as a high-end Steadicam rig. Instead of counterweights, the M10's microcomputer uses signals from gyroscopes and accelerometers to slew motorized gimbals to compensate for the operator's movements. ● Although the M10 is inexpensive by movie-industry standards, it's still too pricey for many low-budget professionals, let alone amateurs. But cheaper stabilizers that work similarly to the M10 will soon be on sale, including the $3000 BeSteady One and the approximately $1800 Ghost, both of which completed successful Kickstarter campaigns in August.

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I don't do much videography, but not long ago I needed to gather footage of an electronic bicycle derailleur in operation [see "Ride By Wire," *IEEE Spectrum*, May 2013]. I cobbled together a home-brew Steadicam for that task, but it tended to "weather-vane," making it hard to keep pointed at the subject. And once it began to wobble, the pendulum-like motions would continue unabated. So an electronically stabilized camera platform seemed an attractive thing for future videos.

But I didn't have thousands of dollars floating around. I did, however, discover that the M10, the BeSteady One, and the Ghost share a common technical heritage: They're handheld versions of the kind of stabilizers that hobbyists use to mount small video cameras under model helicopters. These gimbal systems use brushless DC motors in an unusual mode, one that's akin to microstepping a stepper motor but without the low-speed vibration found with most steppers.

After combing the Web, I settled on what's probably the cheapest example around, one based on a brushless gimbal controller developed by a German group, for which the Arduino-based open-source hardware and software are readily available. Its chief limitation is that it provides only two axes of control—tilt and roll. That's normally all that's needed, because a helicopter can yaw around smoothly, panning an attached camera across the scenery. (Three-axis open-source controllers are available, but they looked immature to me.)

Had I been penny-pinching, I could have purchased brushless motors and a controller board from China and fabricated parts from plywood. But I was anxious to give this technology a try as soon as possible. On eBay, I purchased a $279 kit containing a controller board, a compatible inertial-measurement unit (IMU), two brushless motors, and various aluminum and carbon-fiber parts to complete the rig. Coming from an Ohio-based seller, the package took only a few days to arrive at my door.

I encountered only two problems in assembly, both small: An aluminum cone holding a ball bearing needed an extra screw stuck in the back to work without binding, and the video camera I wanted to use, being on the large side, bashed into the back of the rig. I used a wooden dowel to extend the frame, which worked splendidly.

I downloaded the Arduino code for the controller board, programmed it, and fired up the system, fully expecting it to do strange things. After all, I had attached the three windings of each motor to the controller at random and wasn't even sure how to orient the IMU board when attaching it to the camera. To my astonishment, the thing worked pretty well straight off. I spent a while tuning the feedback loops using some PC software the German group wrote that provides a graphical user interface for this task. But even that didn't take long.

With such a good start, I figured I'd try to adapt this system to control the tilt and pan axes rather than tilt and roll. Then, by adding a video transmitter to the camera and a radio-control receiver to the controller, a second operator can point the camera while the first operator concentrates on keeping it in position, as can be done with the M10. To further imitate that pro-level system, I added a two-handled support, made from a short length of PVC sprinkler pipe (bent with the aid of a heat gun) and a couple of bicycle handlebar grips.

The software had no provision for making this change of axes, but I discovered that all that was really needed was to temporarily disable the accelerometers in the IMU and then rotate the frame, camera, and IMU board by 90 degrees. The system still "thinks" it's controlling roll and tilt, but what was originally the roll axis is now pan. My modified system did suffer some strange couplings between the two axes, though, causing the tilt axis to jitter when I panned the camera too much.

I poked around at the Arduino software in hopes of fixing this issue, but the code is very complicated, and my efforts were to no avail. So I simply disable the tilt-axis motor (by unplugging it) when I want to use the camera in remote-controlled-pan mode, although for reasons I can't explain, smooth panning is limited to plus and minus 60 degrees of the initial heading. Okay, so it doesn't work nearly as well as an M10 rig, but it's still not bad, and it looks almost as cool as one. And what do you want for less than a 50th of the price? —DAVID SCHNEIDER

A version of this article appeared online in October.

STORE-BOUGHT AND HOMEMADE: A commercial kit with brushless motors and a chassis [top] was the basis of the camera mount. A combined radio control and display screen [bottom] allows remote direction.

DAVID SCHNEIDER (3)

CLAMOROUS COMPUTING

Technology should become more self-effacing

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it....Today's multimedia machine makes the computer screen into a demanding focus of attention rather than allowing it to fade into the background.

—Mark Weiser, *Scientific American*, September 1991

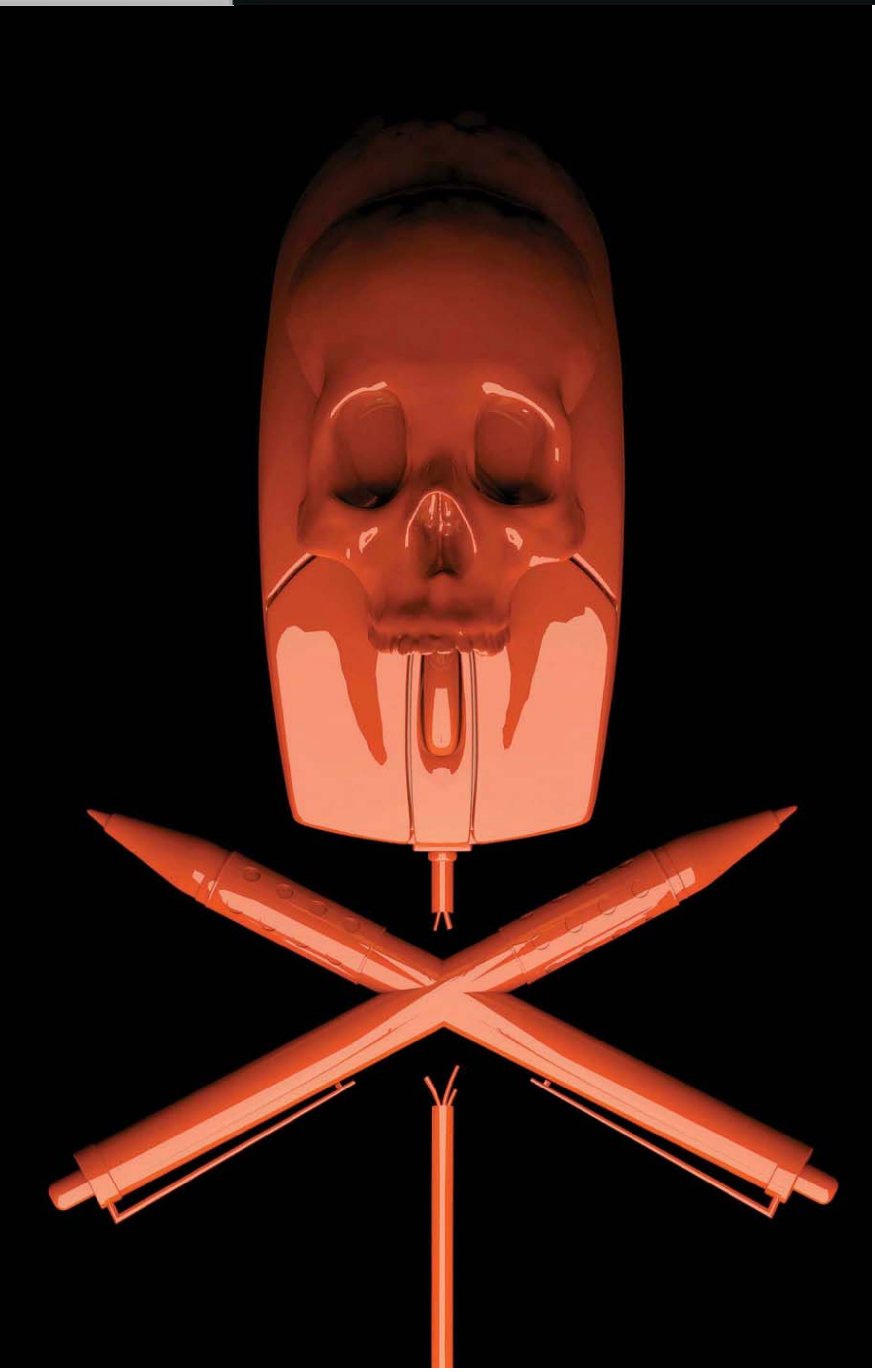
IN 1988, XEROX PARC COMPUTER SCIENTIST (and later CTO) Mark Weiser put forward the idea of–and coined the term–*ubiquitous computing*. Sometimes shortened to *ubicomp*, it refers to the seamless integration of computing resources into most of the objects that people use to perform the activities of daily life. Today we're more likely to call it **pervasive computing** or **everyware**. We're not quite there, despite newfangled appliances such as smart TVs and smart refrigerators, but modern computing does have a pervasive feel to it. That feel comes mostly from the gadgets like smartphones and tablets (and soon, wearables like Google Glass) that we routinely carry around with us. Thanks to cellular connections and Wi-Fi networks, we have near-constant access to computing power and online data, giving us what might be called *near-ubiquitous computing*. It's not quite the **ambient intelligence** envisioned by ubicomp fans, but it's a step or three in that direction. ● There's a problem, however. One of the chief characteristics of true ubicomp is that it is a **calm technology**, meaning that it remains in the background until needed and thus enables us to interact with it in a calm, engaged manner. Today's mobile computing platforms are more like **jittery technology**, constantly beeping at us and alerting us to new messages, posts, updates, and news. (Hence, perhaps, the curious prevalence of **phantom vibration**, the perception of a cellphone's vibration in the absence of an incoming call or notification.) Even watching TV is no longer simple as more and more people use their mobile tech for **second screening** (monitoring social media commentary about the show they're watching) and **chatterboxing** (chatting online with people watching the same show).

If it's by now axiomatic that even as we change technology, it changes us, then we have to wonder how we're being altered by this constant connectivity. On the positive side, having so much information fingertip ready is a boon for productivity and the quick settling of bar bets. On the downside, all this digital **hectivity** leads to **FOMO**, the *f*ear *o*f *m*issing *o*ut on something interesting or fun, which can lead to obsessive checking of social networks. We like to think we're capable of being *polyattentive* (watching or listening to more than one thing at a time), but it's more like what Microsoft researcher Linda Stone calls **continuous partial attention**, where we're ostensibly focused on some task but a chunk of our attention is waiting for something more important to pop up. It's no wonder many people suffer from **nomophobia**, the fear of being without a mobile phone or without a cellular signal. Our phones and tablets have become **weapons of mass distraction**.

The result is the shortened attention span that writer Nicholas Carr identified in his famous 2008 essay, "Is Google Making Us Stupid?" We've become self-interrupters who now routinely suspend our own work to check social media or watch the latest viral video. Conveniently, it *looks* like we're being productive members of society, but in reality our focus on the trivial and the fleeting means we're just being **fauxductive**. We're **social notworking**. True, our brains are engaged, but not always in a good way. We suffer from **busy brain**, a mental state that includes racing thoughts, anxiety, lack of focus, and sleeplessness. We indulge in **binge thinking**, where we overthink problems or think obsessively but fruitlessly over a short period.

Ubiquitous computing remains a technophile's dream–and a utopian one at that, thanks to its vision of technology waiting in the background, not speaking unless spoken to. In its stead we have ubiquitous connectivity–always on, always interrupting, always in your face. And there's nothing calm about that. ■

ILLUSTRATION BY Jesse Lefkowitz



Writing the Rules of Cyberwar

The world needs a Geneva Convention for cyberspace

BY KARL RAUSCHER

I

IN THE 21ST CENTURY, just about everything is vulnerable to cyberattack. A hit on a bank or a stock exchange would cause uproar in the financial sector; a strike on an electrical grid could shut down a city. And the consequences of an attack could be far more dire than mere inconvenience. If hackers disrupted operations at a nuclear power facility, they could trigger a meltdown. An attack on a hospital could leave doctors scrambling in the dark, machines failing, and patients dying in their beds.

Such scenarios are becoming ever more plausible. In 2007 the cyberwar era began in earnest, when Estonia's government networks were hacked during a political dispute with Russia. In recent years, the United States and China have accused each other of sponsoring major cyberintrusions, and Iran has accused the United States and Israel of unleashing a worm against its nuclear installations. Before such activities escalate into cyberattacks that destroy innocent lives, we should apply the lessons of the bitter past and establish the norms of cyberconflict. We should define acceptable targets, and we could even place limits on cyberweapons, just as we did on chemical ones nearly a century ago.

I propose bringing the principles of the Geneva and Hague conventions to bear on cyberconflicts. These conventions, which reached mature form after the First World War, establish rules for the treatment of civilians, prisoners of war, and the wounded, and they also ban the use of certain weapons,

SECURITY

ILLUSTRATION BY Eddie Guy

such as poisonous gas. Preserving these principles is of solemn relevance to billions of people, yet there is still no clear way to apply them to cyberattacks. While it's unlikely that nations could be convinced to sign on to a legally binding treaty, international norms could have the same effect.

To find the way forward, the EastWest Institute has created the Cyber 40, with delegates from 40 digitally advanced countries. Our think tank specializes in back-channel negotiations between countries that don't normally cooperate, and I head the institute's Worldwide Cybersecurity Initiative. We have issued practical recommendations on spam and hacking, many of which have already been implemented. Since we presented our first proposal for "rules of the road" for cyberconflicts in a Russia-U.S. bilateral report at the 2011 Munich Security Conference, the ideas have gained traction. Other groups are also working on the legal issues surrounding cyberattacks—most notably a NATO-related collaboration based in Tallinn, Estonia, which published its findings this March as the *Tallinn Manual*.

In cooperation with industry groups and think tanks in China, Russia, and other countries, we are now trying to define practical humanitarian agreements for cyberconflicts. Such agreements could, for example, designate critical civilian infrastructures like hospitals and electronic medical records as off-limits for cyberattacks. And we hope to at least begin a conversation on whether some cyberweapons are analogous to weapons banned by the Hague and Geneva conventions as offensive to "the principles of humanity and the dictates of the public conscience."

Our international team has reviewed all 750 articles in the Geneva and Hague conventions, in each case asking whether the rule can be transferred directly from the physical world to the cyberworld. Often the situation is simpler in the material world: For example, the difference between routine intelligence gathering and warfare is relatively clear. In cyberoperations, the infiltration of a computer network could be espionage or the prelude to an offensive action—but the mechanism is the same in both cases.

Seemingly straightforward prohibitions, such as the one on attacking hospitals, become complicated when ported to cyberspace. In the physical world, military officials can easily distinguish between a hospital and an army base and can plan their campaigns accordingly. In the cyberworld, everything is intermingled. Hospital records may be stored on a server in a data center that may also store data from a military contractor. In fact, it is the ease with which data and data-searching functions can be distributed across networks that makes cyberspace valuable in the first place.

When we built the Internet, we weren't thinking about how to implement the Geneva Conventions online. To adapt these rules to our era, we must therefore model cyberconflicts, define legitimate targets, and suggest ways of determining compliance with such guidelines.

We will have to mark nontargets in some way. The Geneva and Hague conventions direct that protected entities (such as hospitals and ambulances) and protected personnel (such as medics) be marked in a clearly visible and distinctive way, for instance, with a red cross or red crescent. Marking a hospital's presence on readily available maps constitutes another such warning.

We've been conducting an assessment of special ways to designate protected humanitarian interests in cyberspace. We're currently working with our international partners to evaluate a number of technical solutions to this challenge. For instance, one early idea was to use ".+++" to mark the Internet addresses of hospitals and health databases.

Of course, merely marking protected zones in cyberspace would not stop miscreants from barging into them; then again, neither does the presence of a Red Cross symbol cause a bomb to bounce off a medical clinic. The point is that such markers would allow a state that wanted to comply with the norm to write virus code or arrange attacks so as to avoid designated institutions.

ASSUMING WE CAN DEVISE A SYSTEM to create safe havens on the Internet, another concern is how to get all the necessary parties involved. In the past, the rules of war could gain force if the major nation-states agreed to them. That's not enough to ensure the usefulness of cyberconflict rules, however, because cyberwarriors may be nonstate actors, sometimes even individuals. In order to get those people to respect the rules, we'll need all the world governments to come together to condemn certain acts. Such a consensus would carry enough moral force to isolate any cyberwarriors who cross the line.

I first thought about this question while serving on the National Security Telecommunications Advisory Committee for President George W. Bush. In 2002, when our group met with Vice President Dick Cheney at the White House, one member of the committee asked Cheney which countries the United States should engage with on questions of cybersecurity. His first answer was obvious: the anglophone countries that were eager to partner with us. "But the second answer will really surprise you," he said. We never heard it. At that moment, the Secret Service descended on him and whisked him, and us, away to safety. It was all because of a false alarm that sounded when a small Cessna plane accidentally breached restricted airspace over the White House.

Ever since, I have wondered what Cheney's second suggestion would have been—and my life's work has come down to an attempt to find my own answer. I've come to the conclusion that we have to work with the difficult countries because those are the countries that matter. "Difficult countries" will mean different things to different countries; for the United States, though, the list would surely include Russia and China, both of which are formidable for their technological prowess.

> We could place limits on cyberweapons, just as we did on chemical weapons nearly a century ago

The EastWest Institute's Worldwide Cybersecurity Initiative has therefore begun bilateral processes with experts from the United States and Russia to define the terms used in discussions of cyberconflicts, so that future negotiators will have a clear dictionary to help them differentiate between, for example, cybercrime and cyberterrorism.

We have also brought U.S. and Chinese experts together to produce joint recommendations for fighting spam and botnets—the networks of hijacked computers that are used in some attacks. These recommendations were adopted by the Messaging, Malware, and Mobile Anti-Abuse Working Group, which brings the world's biggest Internet companies together to swap strategies and collaborate on projects. Most recently, we've worked with our Chinese counterparts to issue recommendations on how to resolve conflicts over hacking. With these efforts, we've prepared the way for extending the humanitarian principles of the Geneva and Hague conventions into cyberspace.

IT HAS SOMETIMES been argued that international norms are toothless—that countries resort to chemical and biological attacks rarely only because they fear facing retaliation in kind. However, recent events in Syria's civil war show that norms do matter. The Syrian government, which is not party to the Chemical Weapons Convention, nevertheless felt the world's wrath when it allegedly used poison gas against rebel forces and civilians. The United States first threatened to intervene in the war to protest the action. However, that threat was revoked when the regime's allies—notably Russia, which was on record as opposing chemical warfare—devised a plan to take away Syria's chemical weapons.

This case illustrates some of the problems that would face any attempt to enforce the norms of cyberwarfare, most obviously the problem of tracing an attack to its perpetrator. The Syrian government maintained that it had not broken international laws against chemical warfare, and some observers agreed that it wasn't completely clear who had done the deed. It could even have been a provocation or, perhaps, a blunder on the part of the rebel commanders. Happily, the international community was able to agree on a practical remedy despite the lack of hard proof.

If we can set the parameters of basic human decency in time of cyberwar, then maybe we can ban aspects of such warfare altogether. At the least, we can discuss taking some cyberweapons off the table. Some of them do, after all, carry the potential for viral behavior, with a lack of discrimination regarding targets, and they all travel at computer speeds. These attributes, combined with a belligerent cause, are an understandable reason for concern.

We can bring the principles of the Geneva Conventions into the 21st century if we agree that these rules are worth preserving and agree that war need not be the infliction of maximum suffering on the enemy. Some may call me naive, but I believe mankind can be civilized even as we engage in a new era of cyberconflicts. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/cyberwar1213

ESPIONAGE, SABOTAGE, AND MORE

In the past decade, cyberattacks have changed from theoretical concerns to urgent national priorities. While the bulk of attacks target private companies for economic gain, here's a roundup of attacks that may have been launched with political intent.

STUXNET TARGET: Iran's Bushehr nuclear power plant took a hit.

2007 In Estonia, the websites of some government agencies, financial institutions, and newspapers are shut down by **denial-of-service attacks** during a political spat with Russia.

2008 During the run-up to the U.S. presidential election, e-mails containing **malware** are sent to top aides in the campaigns of both Barack Obama and John McCain, and internal position papers and e-mails are accessed. The U.S. government blames foreign hackers.

2008 In the weeks before the Russia-Georgia war, Georgia's Internet infrastructure and some government websites are hit with a **denial-of-service attack**.

2009 In a vast spy campaign known as **GhostNet**, e-mails containing malware are used to take control of computers in dozens of embassies, foreign ministries, and Tibetan exile centers around the world. The researchers who discover GhostNet believe it's controlled by Chinese networks.

2010 Iran's nuclear facilities are sabotaged by the **Stuxnet** worm in one of the first uses of offensive cyberweapons. During an investigation by *The New York Times*, many unnamed officials say that the United States and Israel created the worm.

2010 One month after the websites of many Pakistani government ministries are **shut down and vandalized**, with Indian hacker groups claiming credit, the websites of Indian security agencies are similarly attacked by Pakistani hackers.

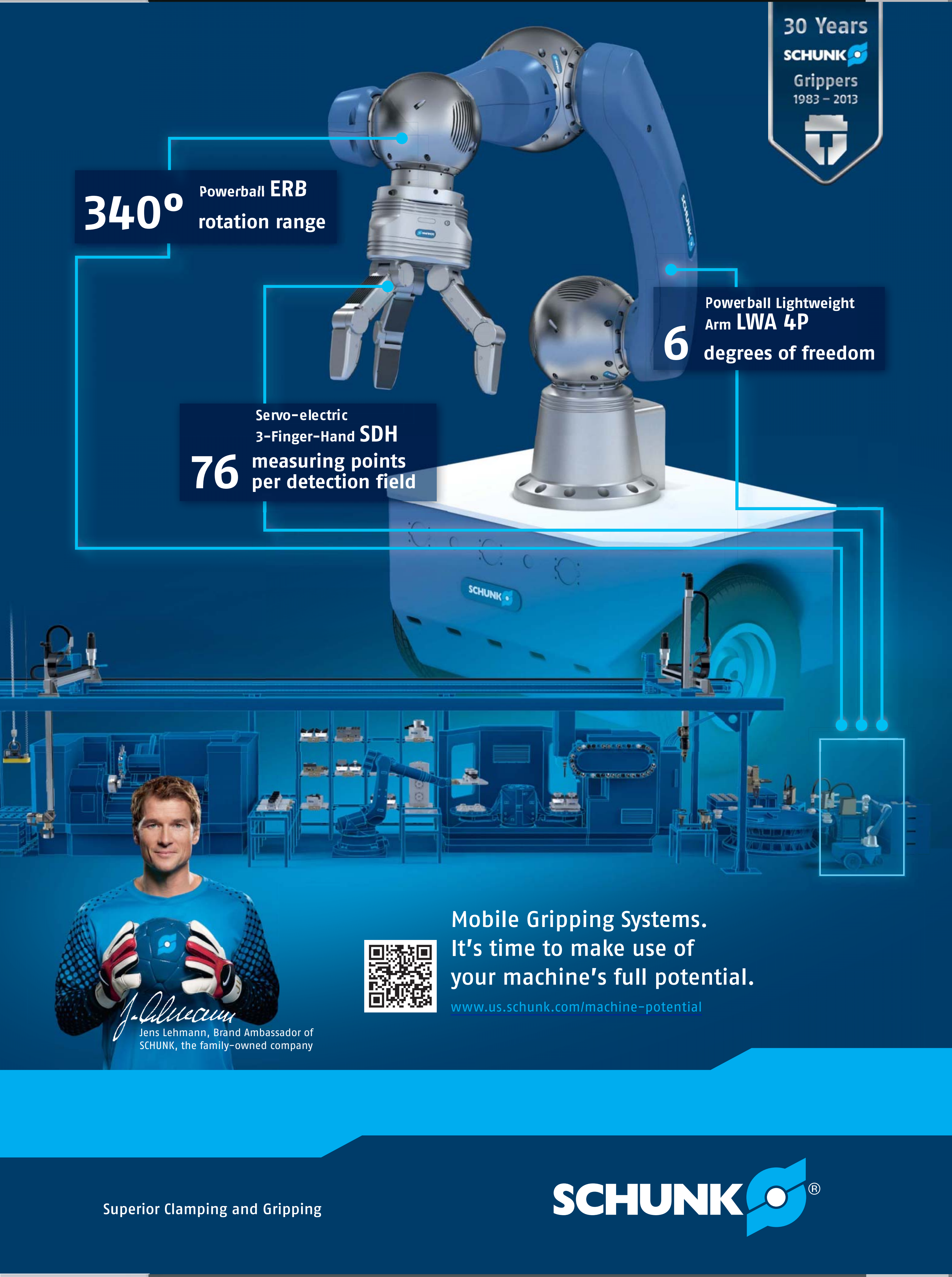
2011 The Canadian government has to disconnect its two main economic agencies from the Internet when a **computer virus** sweeps through government networks, seeking out classified documents and sending them back to hackers. The attacks are traced as far back as computer servers in China.

2012 A malware program known as **Flame** is discovered in computers across the Middle East, with the majority of targets in Iran. The sophisticated cyberespionage program shares some source code with Stuxnet but is described by experts as being far more complicated.

2013 Operations at several South Korean television stations and major banks are disrupted when a malware program known as **DarkSeoul** renders computers unusable. Many experts speculate that North Korea is responsible.

IIPA/GETTY IMAGES

SECURITY


30 Years
SCHUNK
Grippers
1983 – 2013
340° Powerball ERB
rotation range
6 Powerball Lightweight
Arm LWA 4P
degrees of freedom
Servo-electric
3-Finger-Hand SDH
76 measuring points
per detection field
Mobile Gripping Systems.
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You Are Here

THE PERVASIVE LOCATION AWARENESS WE'VE LONG ENJOYED OUTSIDE IS SLOWLY FINDING ITS WAY INDOORS • BY DAVID SCHNEIDER

TODAY YOU CAN EASILY FIND YOUR WAY to, say, the nearest Starbucks in a strange city, thanks to a cascade of events that began a little more than 30 years ago, when a Soviet Sukhoi interceptor flying high over the Sea of Japan fired off two heat-seeking missiles. The long-term result: You now have no trouble locating a cappuccino. ¶ Of course, you're not finding that coffee by the heat it gives off. You are most likely guided to it in missile-like fashion by the GPS receiver in your smartphone or on your dashboard. That ubiquitous piece of consumer technology works—indeed exists—only because the U.S. Department of Defense allowed civilian use of its satellite-based positioning system. That wasn't the original plan. The Global Positioning System was supposed to be exclusively for soldiers, sailors, and airmen, until President Ronald Reagan ordered a sudden change in policy in response to the deaths of 269 people aboard a Korean airliner that veered into Soviet territory on 1 September 1983. Believing it to be a military aircraft on a spying mission, Soviet air defense forces shot it down.

ILLUSTRATION BY Bryan Christie Design

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YOUR SMARTPHONE DOCENT: Wifarer, based in Victoria, B.C., Canada, produces smartphone apps for indoor positioning based on Wi-Fi signals. One of the company's custom apps guides visitors around the Royal BC Museum (also in Victoria), helping them find their way and understand the exhibits.

ROYAL BC MUSEUM

The Department of Defense dutifully carried out Reagan's instructions to make GPS signals available for civilian uses, but it hedged at first, adding random timing errors to the satellite signals accessible to nonmilitary GPS units so they could determine locations to no better than 100 meters. Then in 2000, after President Bill Clinton ordered this purposeful degradation to be stopped, the error circle shrank to 10 meters or so. All of a sudden, GPS became extremely valuable for vehicle and even pedestrian navigation.

Those shifts in U.S. policy, along with the plummeting cost of GPS chip sets and the proliferation of smartphones, ended up putting formidable satellite-navigation capabilities in almost everyone's pocket. The rub is that radio signals coming from distant satellites can't help where the view of the sky is obstructed, which makes navigating in narrow canyons, urban or otherwise, tough going. And these high-frequency signals bounce around so much when they hit metal that getting a good GPS fix indoors usually proves impossible.

It's a huge problem, one that radio engineers are keen to solve. They've been pursuing a host of different strategies to help us find our way about indoors and also to track movable assets—hospital equipment, specialty tools on the factory floor, mobile robots, livestock, you name it. Here are the technical underpinnings of the leading possibilities, along with some educated guesses as to how they will pan out.

"INDOOR NAVIGATION is very, very tricky," says Kaveh Pahlavan, a professor of electrical and computer engineering at Worcester Polytechnic Institute, in Massachusetts. As director of the Center for Wireless Information Network Studies, he has closely followed the various radio-based positioning methods that have emerged over the years and watched how these technologies have shaken out. Often, he notes, progress isn't just a function of technical promise. Business realities regularly trump that. "The fact is, what industry selects is important," he says. "Today, Wi-Fi localization is the most popular."

Boston-based Skyhook Wireless, which Pahlavan advises on technical matters, is one of many companies offering positioning based on Wi-Fi (and cellular signals and GPS, where those are also available). The company maintains a huge database of the often-changing geographic locations of Wi-Fi access points by hiring an army of "wardrivers"—people who drive around while recording Wi-Fi signals and GPS positions. A user with a handset running one of the Skyhook-enabled apps can then apply the company's various proprietary algorithms to gauge position based on which of the mapped access points are within range and how strong the received signals are. The beauty of this approach is that it requires no additional infrastructure, and any Wi-Fi-equipped phone, tablet, or laptop can be used without modification. That's why the original iPhone and iPod Touch models (which lacked GPS receivers) used Skyhook for position estimation.

How good are the position fixes? Skyhook's tests show typical indoor accuracies of 3 to 10 meters. That's better than GPS manages outdoors, but it still could easily misidentify the room you're in or the floor you're on. Accuracies can be improved, though, by adding more access points and carefully charting the radio environment within a building of interest. That's what Wifarer, for example, of Victoria, B.C., Canada, does to produce site-specific Android and iOS apps for displaying position-dependent information. Impressively, its app users were able to pinpoint their locations to within about a meter and a half, on average, at the Royal BC Museum, where the company rolled out its system last year.

BEING ABLE TO FIX indoor positions to within a couple of meters is great for finding your way around museums, airports, con-

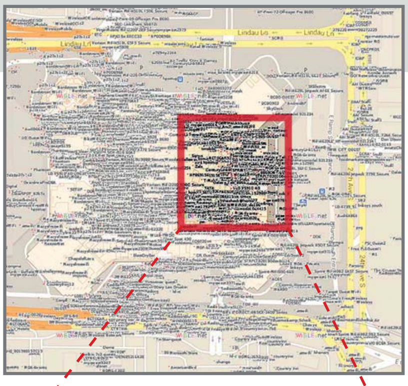
BEACONS OF OPPORTUNITY

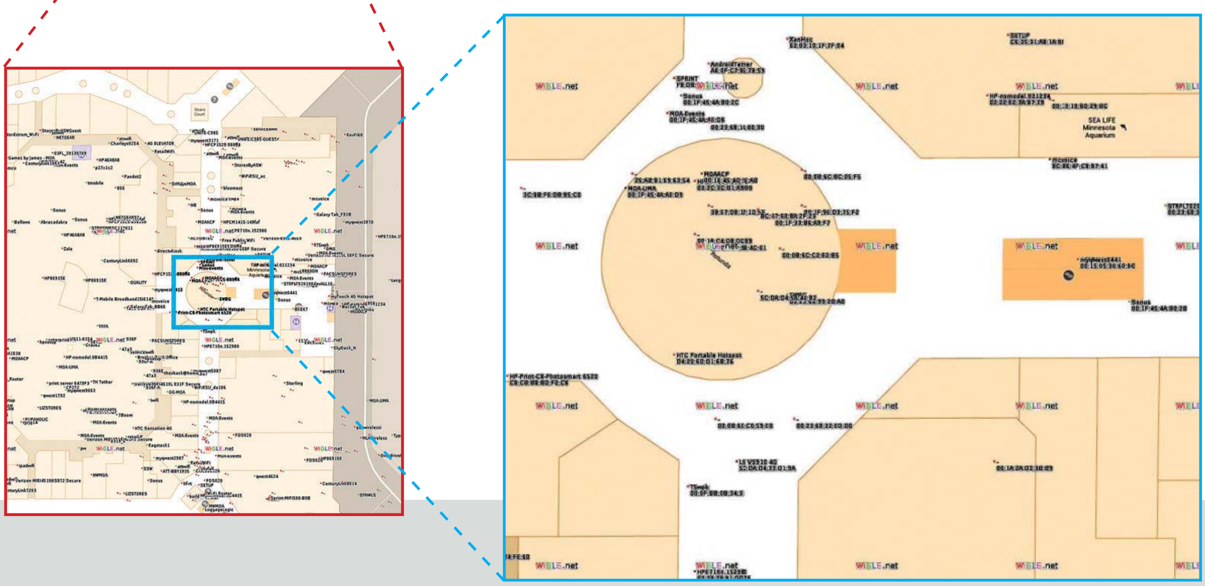
GOOGLE BEGAN providing Android users with navigational aids at certain popular indoor locales two years ago. One of the first locations to be electronically charted in this way was the Mall of America, located in Bloomington, Minn. As the most visited shopping mall in the United States, the Mall of America receives more than 40 million visitors each year, many of whom no doubt get lost wandering in its cavernous interior.

GPS signals don't work well in such settings, and positions calculated using transmissions from cell towers would be awkwardly imprecise. As a consequence, the location-finding abilities of Google Maps depend heavily on broadcasts from the mall's many Wi-Fi access points.

Google's Wi-Fi database is proprietary, but WiGLE (Wi-Fi Geographic Location Engine), which contains data on more than 100 million access points, provides some sense of where they can be found.

WiGLE locations for Wi-Fi access points at the Mall of America [shown in the panels below] could be significantly off, and in any event they're not particularly up to date. So please note that this illustration should *not* be used for navigation.





MAP: GOOGLE; WI-FI LOCATIONS: WIGLE.NET

vention centers, or malls, but it's not adequate for many other situations. Imagine that you're designing a mail-delivery robot. A location error of just 2 meters will have it, and you, bouncing off the walls. And the Wi-Fi strategy doesn't work at all for first responders–say, firefighters trapped inside a burning building. [See "The Way Through the Flames," *IEEE Spectrum*, September 2013.] If you're willing to install radio equipment designed specifically with positioning in mind, though, there's no shortage of options.

One company offering help with that is Q-Track, based in Huntsville, Ala., which claims its indoor radiolocation system can provide submeter accuracy. It uses frequencies of about 1 megahertz, which is considerably lower than Wi-Fi. Why? "You want to have a signal that can get through a messy propagation environment," says Hans Schantz, cofounder of Q-Track. Low frequencies can more easily penetrate the many barriers found indoors. They diffract less around obstacles, and they don't fall prey to the multipath phenomenon, whereby the different waves caroming around inside a building interfere with one another.

Q-Track's system differs from Wi-Fi localization in another fundamental way: It doesn't use signal strength to gauge the distance between transmitter and receiver. Nor does it measure the time it takes the signal to travel from transmitter to receiver, as GPS does. Instead, it cleverly exploits the fact that at frequencies of a megahertz or so, and at building-size distances (say, up to 100 meters), the receiver operates in what radio engineers call the near field of the transmitter.

In this special zone, the emanations from a radio antenna are rather peculiar. The electric and magnetic fields do not rise and fall in lockstep, for example, as is normally the case with radio waves. And the difference in their timing (their relative phase) is, conveniently enough, a function of the distance from the transmitting antenna.

Q-Track uses the distance-dependent difference in phase, as well as other features found only in the near field, to calculate the location of a transmitter tag with respect to fixed receivers. Those receivers are fitted with antennas that can separately measure electric and magnetic fields. Outdoors, the system is accurate to 15 centimeters, but indoors, the structural elements of a building produce errors of as much as several meters. But by mapping out the site's radio environment first, says Schantz, the system can locate one of its tags indoors to within 40 cm.

Although that might seem as precise as you'd ever need, applications like robot navigation demand even better. Also, Q-Track's receiving equipment is bulky, and its tags

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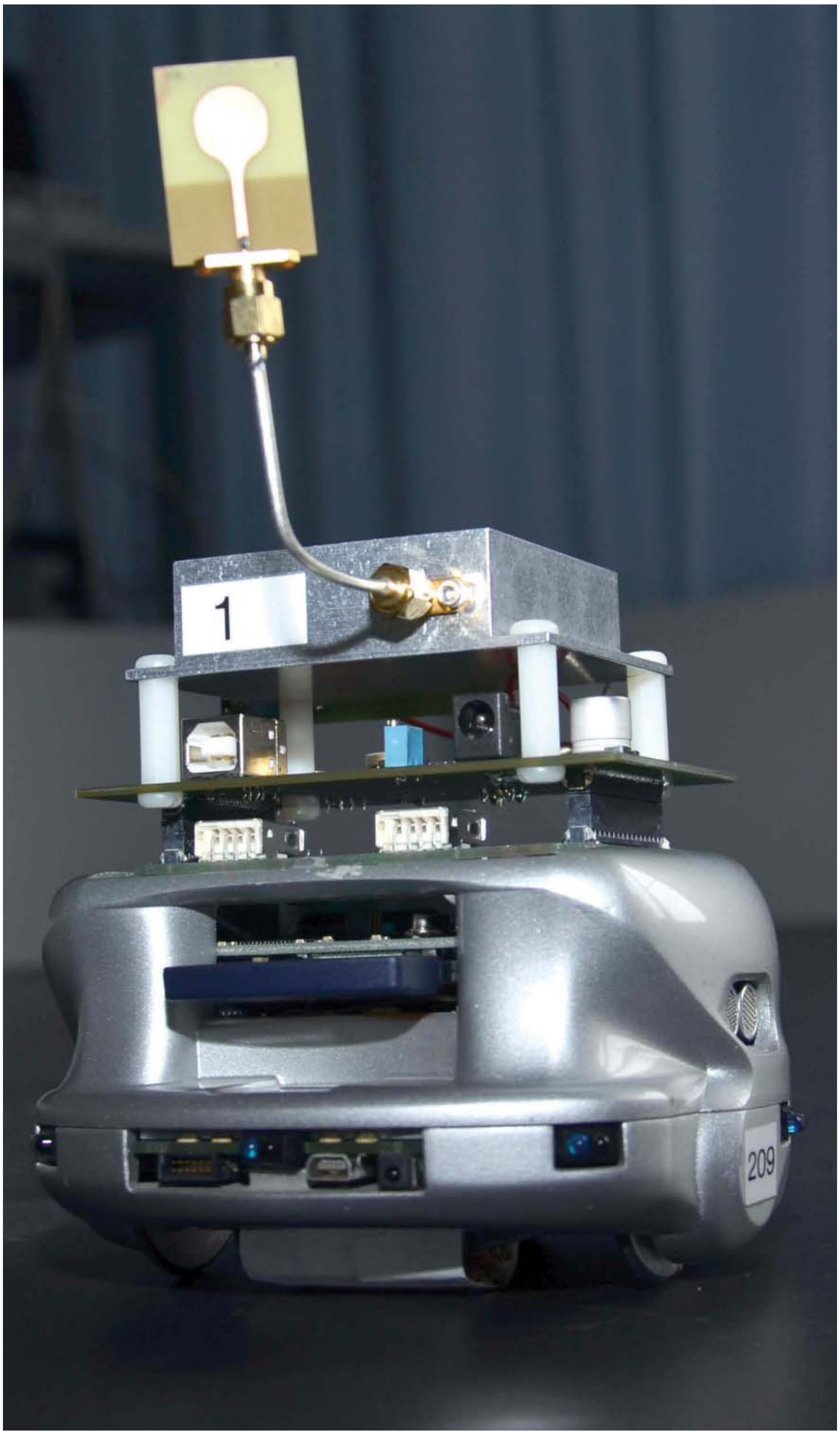

MOBILE ROBOT FINDER: Researchers are studying ultrawideband location systems for mobile robots, hoping to overcome the degradation in accuracy that arises when the signals do not follow line-of-sight paths.

ALEXANDER FELDMAN

are power hungry. Even with rechargeable lithium-ion batteries, they last at most a few weeks. So while the system works well in some settings, it's hard to see it going into countless key fobs, cellphones, RFID tags, and wireless access points, which is what would be required for indoor positioning to become truly ubiquitous.

ONE COMPANY HOPING to overcome those hurdles is DecaWave, a Dublin-based fabless semiconductor manufacturer that has just released a wireless-networking chip designed to provide extremely precise indoor locations. It uses very brief bursts of radio energy, akin to those emitted by some radars, and can measure the time it takes these pulses to travel between radios to a fraction of a nanosecond, allowing distances to be determined to better than 10 cm. The brevity of the emitted pulses ensures that multipath interference won't cause problems, because the reflected pulses are well separated in time from those taking the direct path between transmitter and receiver. It also means that the transmissions have a very large spectral bandwidth—about 500 MHz wide for DecaWave's new product—which is why its chip belongs to a category of radio technology called ultrawideband.

Transmitting in short bursts harks back to the earliest days of radio, when the pulsating signals from primitive spark-gap transmitters splayed energy all over the spectrum, conveying a little bit of information while creating a great deal of electromagnetic havoc. Radio's first regulatory authorities, eager to impose some order, put a stop to this flagrant waste of bandwidth a century ago. The operative paradigm since then has been to divvy up the frequency spectrum into narrow slices allotted to this or that application, with companies often paying handsomely for their radio privileges. So finding a suitable 500-MHz chunk over which to operate in today's crowded spectrum might seem a practical impossibility.

In fact, it's not. If power levels are kept low enough, ultrawideband transmissions, being so thinly spread out in frequency, can share the airwaves with conventional radio services without causing interference. Those services have long had to cope with the incidental energy given off by electric motors, automobile ignition systems, and all sorts of digital gadgets that aren't intended to transmit radio waves. Low-power ultrawideband transmissions are no more menacing, which is why radio authorities around the world are now embracing this technology. As with many paradigm shifts, though, it's been a long time coming.

The U. S. Federal Communications Commission first moved to allow ultrawideband radio back in 1998, when it was being promoted for short-range, high-speed data links. Spectrum users howled in protest, claiming it would interfere with their equipment. The agency has since systematically reviewed and pretty much discounted these objections, but ultrawideband long lacked industry standardization, so it struggled to gain traction.

DecaWave is counting on an ultrawideband version of the IEEE 802.15.4 standard used in ZigBee low-power wireless networks to propel it forward. That version incorporates ideas that DecaWave's cofounder and chief technology officer, Michael McLaughlin, brought to the table in the mid-2000s. The resulting 802.15.4a standard, first ratified in 2007, includes provisions for both sending data and measuring distance precisely.

DecaWave isn't the only company betting on ultrawideband radio for indoor positioning, but it's the only one staking its fortunes on the development and mass marketing of a low-cost transceiver chip, one that's small enough and cheap enough for cellphone and access-point manufacturers to adopt without a lot of fuss. "When we started the company, we said we wanted to be the next Qualcomm," says Ciaran Connell, DecaWave's cofounder and chief executive officer. "We got laughed at so much, we started saying we wanted to be the next Cambridge Silicon Radio. People seemed to accept that."

Should DecaWave's chips one day make it into everyone's phones and access points, it would remove a big barrier—the hassle and expense of having to install in countless buildings radio equipment specifically designed to enable indoor positioning.

DESPITE THE PROMISE of DecaWave's newly released ultrawideband chip—and the existence of earlier ultrawideband location equipment from companies such as Berlin-based Nanotron, Time Domain of Huntsville, Ala., and Zebra Technologies of Lincolnshire, Ill.—Pahlavan remains skeptical. "Indoor geolocation doesn't yet have a good solution, including ultrawideband," he says. He bases this view, in part, on a bit of history.

After the battle of Mogadishu, in Somalia, in 1993 (a debacle that was the basis for the book and film *Black Hawk Down*), it became abundantly clear that soldiers needed something better than GPS to find their way around during combat in urban settings. The following year, the U.S. Defense Advanced Research Projects Agency began work on what was known as the Small Unit Operations Situational Awareness System. That sparked a great deal of interest in ultrawideband radio, which in principle could provide soldiers with both low-power, hard-to-jam communications and precision positioning capabilities. The U.S. government poured many millions into this program, yet the ideal positioning system never emerged.

The fundamental problem, according to Pahlavan, is that ultrawideband signals can get blocked too easily. In the various indoor environments he and his students have tested,

> **HYBRID SCHEMES** will take advantage of every radio source available: **Wi-Fi** in particular but also **cellular signals, Bluetooth, television broadcasts, even ultrawideband sources,** if these become commonplace.

this happens, on average, 40 percent of the time. So it's impossible for an ultrawideband receiver to determine whether the first pulse it detects followed a straight-line path from the transmitter or bounced off one or more surfaces first. The latter would, of course, throw off the calculated position.

In a study of an ultrawideband location system conducted at the University of Bologna's WiLab, in Italy, researchers found that the absence of signals following a direct path (or the delay that straight-line signals experience as they pass through thick masonry walls) can easily create errors of a meter or two. That's similar to what Time Domain and Honeywell found in testing an ultrawideband positioning system meant for emergency responders, which proved good to about a meter. While that level of precision is just fine for most applications, it's not much better than what can be achieved with systems using measurements of Wi-Fi signal strength. So it's unclear whether ultrawideband location systems will catch on for anything other than line-of-sight applications or for those rare indoor settings where Wi-Fi signals aren't present and you have to set up radio beacons anyway.

IF NOT ULTRAWIDEBAND, then what? "Nobody knows the solution," says Pahlavan. "People are waiting for the holy grail." His best guess is that mass-market indoor positioning will continue to improve slowly, using hybrid schemes that take advantage of every radio source available: Wi-Fi in particular but also cellular signals, Bluetooth, television broadcasts, even ultrawideband sources, if these become commonplace.

And these hybrid positioning systems need not be restricted to using radio. They'll probably incorporate measurements from the accelerometers and gyroscopes found in smartphones to add inertial navigation to the mix—a strategy both Qualcomm and Apple have shown interest in of late. (This past March, Apple purchased the Stanford University spin-off WiFiSLAM, which is working on ways to squeeze precise indoor navigation out of ordinary smartphones.) Pressure sensors will also be used to establish height above ground, and at least one company—IndoorAtlas, based in Oulu, Finland—thinks that a smartphone's magnetometer measurements could help reveal positions indoors. "Indoor geolocation is a multidisciplinary thing," says Pahlavan.

So don't bet on a single silver-bullet technology to solve the problem of indoor navigation. Instead, expect a lot of belt-and-suspenders activity, with mobile units sensing their surroundings in every way possible, uploading the results to location-calculating engines in the cloud, and getting their positions continually reported back. And all this real-time indoor positioning won't be reserved just for people and their phones—the Internet of Things will no doubt have location-finding abilities as well. That mug of coffee you're seeking will soon have nowhere left to hide. ■

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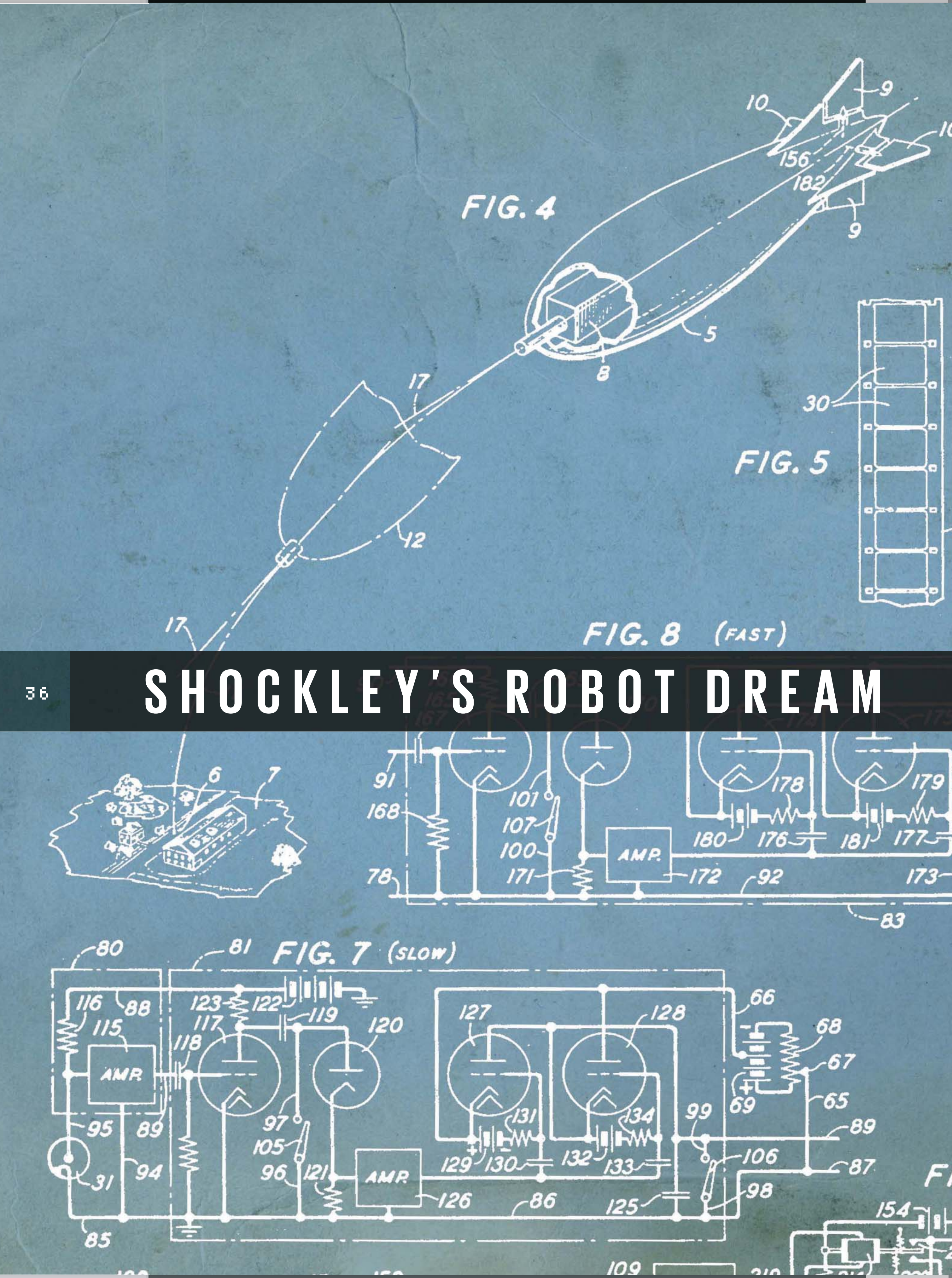
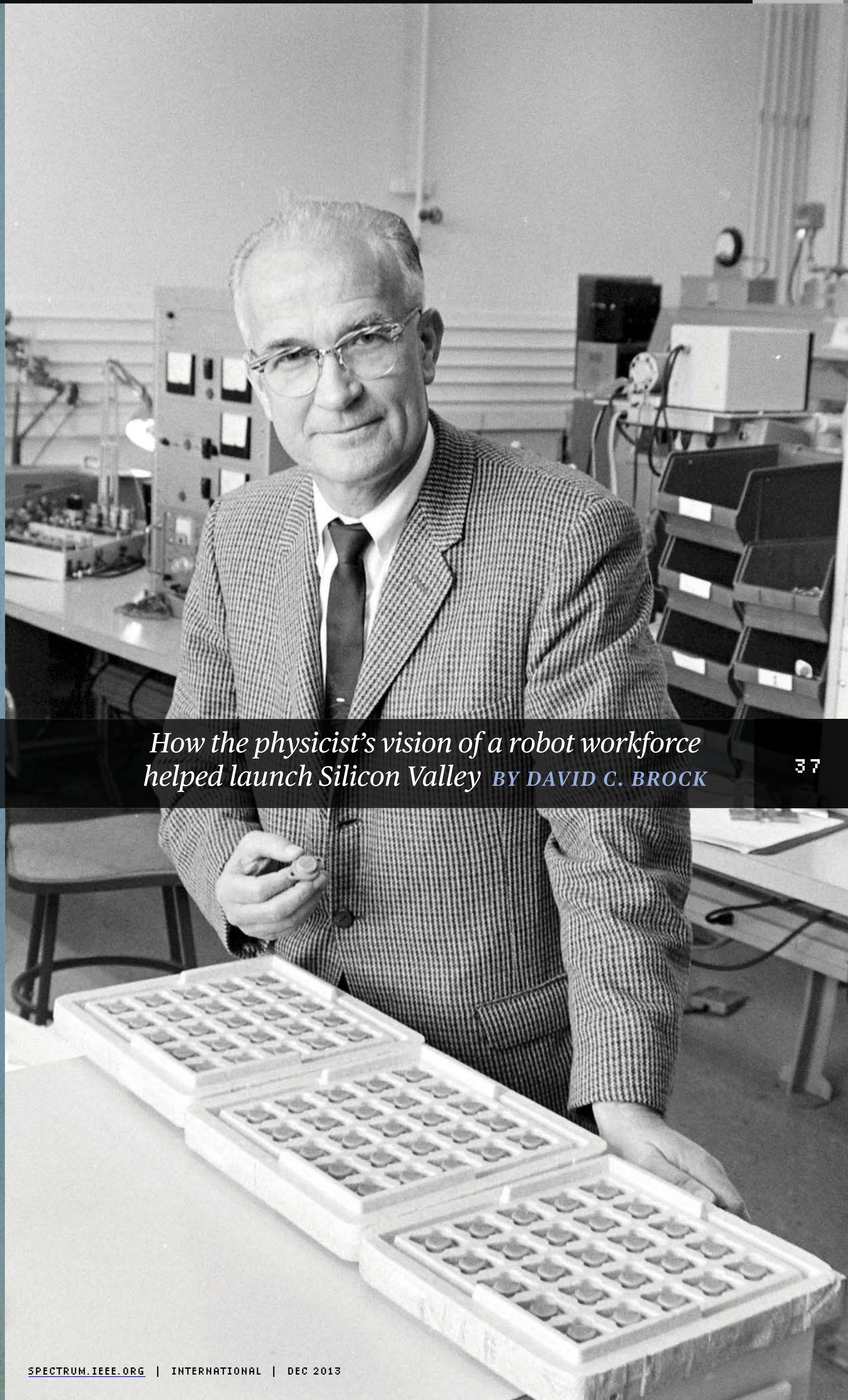
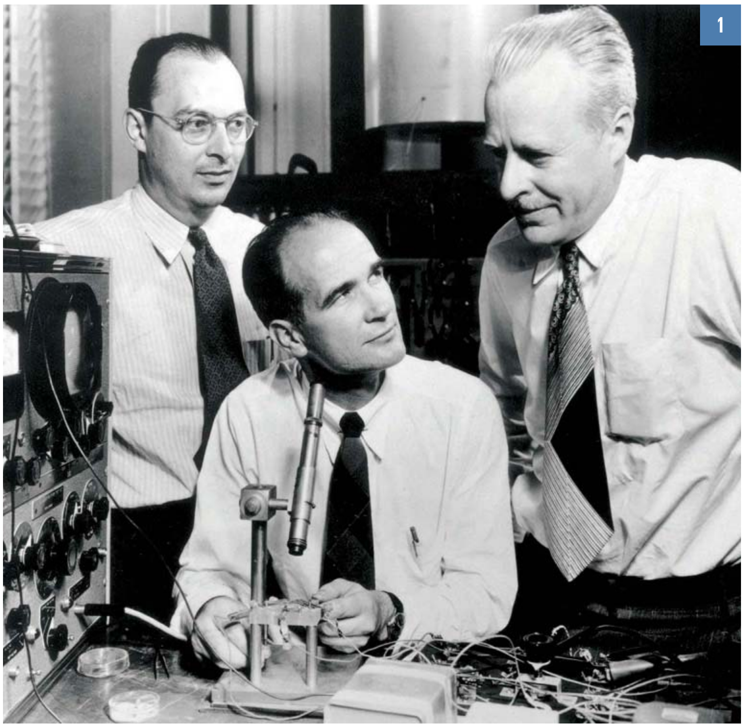


SHOCKLEY'S ROBOT DREAM



How the physicist's vision of a robot workforce helped launch Silicon Valley BY DAVID C. BROCK



BIG EVENTS: 1) John Bardeen [left] and Walter Brattain [right] create the point-contact transistor in 1947; William Shockley [center] conceives the junction transistor in 1948. 2) In 1948, Shockley also patents an automated vision system, which venture capitalist Georges Doriot [shown] later urges him to develop. 3) Shockley then tries to get Arnold O. Beckman [far right] to take up his automation ideas. 4) Beckman declines, but in 1955 he and Shockley create a silicon electronics lab. The next year, Shockley celebrates with his staff after winning the Nobel Prize.

THE PROVERB "SUCCESS HAS MANY FATHERS" is rarely clearer than in the many stories about the rise of Silicon Valley and the diverse web of people, institutions, resources, and dynamics that transformed the San Francisco Peninsula into an astonishingly intense locus of technological activity. Several threads of this web are now legend: Dave Packard and Bill Hewlett's garage workshop, the tireless networking of Stanford engineering dean Fred Terman, the audacious young scientists and engineers who founded Fairchild Semiconductor Corp. and later Intel Corp. Other threads are just as critical but less well known, like the electron and microwave tube industry of the 1940s and the tremendous growth in military aerospace efforts in the '50s.

But one intriguing thread has been entirely forgotten, if it ever was really known. It connects the Nobel Prize-winning physicist William B. Shockley, the chemist and industrialist Arnold O. Beckman, the automation craze of the 1950s, and Shockley's vaulting imagination of a robotic workforce. Shockley's pursuit of that vision, and his desire to profit from his own ideas, led him to leave a successful career at Bell Telephone Laboratories to pursue a company of his own on the West Coast. There, Shockley forged a partnership with Beckman and created his silicon electronics lab–the region's first–in Mountain View, Calif., thereby seeding the dramatic transformations that would eventually lead to the emergence of Silicon Valley as the global epicenter for silicon electronics.

THE PLOT BEGINS IN 1948, a time of creative ferment for Shockley. That year, the 38-year-old Bell Labs researcher conceived the junction transistor, which quickly became the predominant type in the 1950s and 1960s. The first pocket transistor radios had junction transistors, as did the intercontinental ballistic missiles and bombers of the early Cold War. The invention cemented Shockley's reputation as one of the foremost minds in the new world of semiconductor electronics.

Against that backdrop, then, what else was occupying Shockley's thoughts? As it happens, 1948 was also the year that Shockley filed a patent application for a "Radiant Energy Control System"–basically a feedback control system that used a visual sensor. The design had nothing to do with transistors and everything to do with Shockley's military work during the Second World War, especially his efforts to improve strategic bombing. He filed the application on 19 March, and it was quickly met with a patent secrecy order, remaining under wraps for a decade.

Figure 4 of the application makes clear the government's concern: It depicts what appears to be a self-guided bomb falling on a factory. Housed in the nose of the bomb, Shockley's guidance system would compare a series of photographic images–on a roll of film, for instance–with real-time images captured by a camera. Light entering the camera would pass through a frame of the film before falling on light-sensitive vacuum tubes. The better the match between the incoming image and the photographic frame, the larger the electrical signals. These signals, in turn, controlled servomotors that moved the fins of the bomb in a feedback loop. In his illustrated example, the film consisted of a series of aerial photographs of a military target taken at various altitudes. His control system would fly the bomb to that target.

Shockley also noted peaceful uses for his invention: facial recognition for access to buildings, identification of money in vending machines, and, intriguingly, "in factory production to sort items and inspect them." This is perhaps Shockley's first serious imagining of a machine, self-guided

PREVIOUS PAGES: LEFT, U.S. PATENT & TRADEMARK OFFICE; RIGHT, ROBERT W. KELLEY/TIME & LIFE PICTURES/GETTY IMAGES


4

by feedback control and a visual sensor, to replace factory workers.

The idea of replacing humans with machines was nothing new, of course. From the Great Depression, through the war, and into the Cold War, the nexus of labor and manufacturing technology was a continual source of both innovation and conflict. When Shockley filed his patent application in 1948, there was widespread concern among the U.S. business elite that organized labor had become too powerful: Union membership had soared during the war, as had the number of strikes. Many in government and industry also worried that the United States lacked the industrial might of the Soviets. Clever, electronics-infused, self-guided machinery promised a solution to both concerns.

In fact, a word had recently been coined for precisely this solution: *automation*. Delmar Harder, a manufacturing leader at Ford Motor Co., used the word to describe a new class of machinery that could autonomously move materials from process to process along a production line. John Diebold, a graduate of the Harvard Business School, soon popularized the term and the idea with his 1952 best seller, *Automation: The Advent of the Automatic Factory*. In it, he described how new technologies coming out of the war–electronics, feedback controls, instrumentation, and electronic computers–could bring about an age of smart, adaptive, programmable factories that operated largely on their own. He believed this automation revolution was close at hand.

And yet, Diebold distanced automation from the idea of the humanlike robot. He asserted that such robots made little economic sense, even if they could be fashioned. William Shockley disagreed.

TWO YEARS AFTER filing his now-secret patent application, Shockley met with Georges Doriot, a respected professor at the Harvard Business School and Diebold's mentor. Doriot was also a pioneer in venture capital whose American Research and Development Corp. (ARDC) invested in high-tech spin-offs from MIT; its biggest winner would be Digital Equipment Corp.

Doriot and Shockley's discussion turned to automation, a subject then gripping the MIT community following the publication of Norbert Wiener's influential 1948 book, *Cybernetics*. Shockley saw that his control system could be a key technology in such a milieu. Doriot encouraged Shockley to think hard about the full implications of his invention for manufacturing.

Shockley wasted no time in doing so. By the start of 1951, he'd modified his designs and created what he called an "optoelectronic eye." With it, he believed that a new class of machines could flexibly produce different products, not just handle continuous runs of fixed, standardized units.

Before formally recording his ideas, Shockley requested an extraordinary "modification agreement" to his intellectual property contract with Bell Labs. Shockley, like everyone else at the labs, had signed an employment agreement that gave the company the rights to all of his patentable inventions. Now he wanted Bell Labs to let him patent for himself his new optoelectronic eye for automated production.

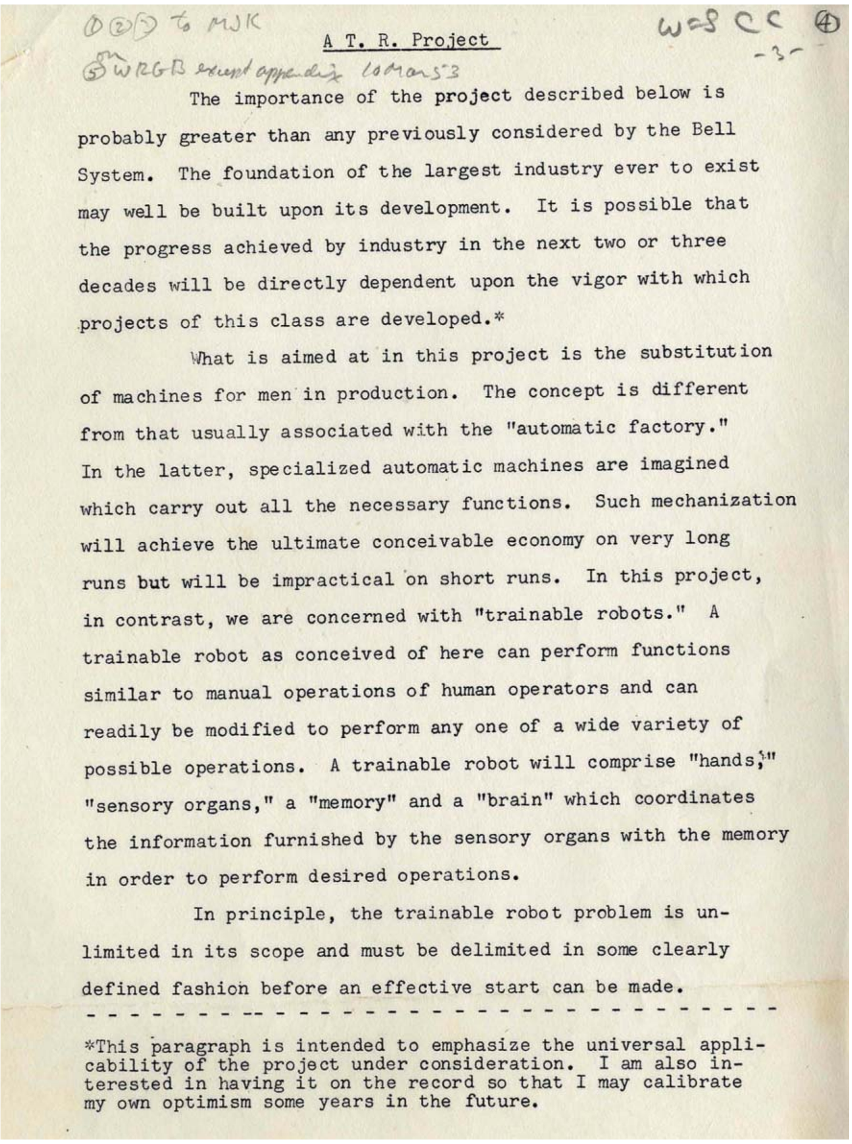
After months of negotiation, Bell Labs and Shockley finally signed the agreement on 5 December 1951. But the new agreement gave the company an important out: It would last for just one year and was strictly limited to automation. During that time, Shockley could patent what he could–and claim any resulting benefits across the lives of those patents–but after it expired, it would be as if the agreement never existed.

With support from Doriot's ARDC, Shockley completed his patent application for an "Electrooptical Control System." Even before he was finished, however, he was feeling confident enough in his idea to write a remarkable memo to Bell Labs' president, the physicist Mervin Kelly. The memo argued that Bell Labs should undertake a large, high-priority effort, led by Shockley, to create an "automatic trainable robot."

"The importance of the project described below is probably greater than any previously considered by the Bell System," Shockley declared. "The foundation of the largest industry ever to exist may well be built upon its development. It is possible that the progress achieved by industry in the next two or three decades will be directly dependent upon the vigor with which projects of this class are developed." Even for the notably self-confident Shockley, this was forceful language.

"What is aimed at in this project is the substitution of machines for men in production," he continued. He made it clear that he wasn't talking simply about advanced machines for an "automatic factory." He was talking about the robots of science fiction. Shockley's trainable robots would perform the "manual operations of human operators" and "be readily modified to perform any one of a wide variety of operations." Such robots could replace

CLOCKWISE FROM LEFT: HULTON ARCHIVE/GETTY IMAGES; CHEMICAL HERITAGE FOUNDATION COLLECTIONS; INTEL MUSEUM; BETTMANN/CORBIS



A T. R. Project

-3-

The importance of the project described below is probably greater than any previously considered by the Bell System. The foundation of the largest industry ever to exist may well be built upon its development. It is possible that the progress achieved by industry in the next two or three decades will be directly dependent upon the vigor with which projects of this class are developed.*

What is aimed at in this project is the substitution of machines for men in production. The concept is different from that usually associated with the "automatic factory." In the latter, specialized automatic machines are imagined which carry out all the necessary functions. Such mechanization will achieve the ultimate conceivable economy on very long runs but will be impractical on short runs. In this project, in contrast, we are concerned with "trainable robots." A trainable robot as conceived of here can perform functions similar to manual operations of human operators and can readily be modified to perform any one of a wide variety of possible operations. A trainable robot will comprise "hands," "sensory organs," a "memory" and a "brain" which coordinates the information furnished by the sensory organs with the memory in order to perform desired operations.

In principle, the trainable robot problem is unlimited in its scope and must be delimited in some clearly defined fashion before an effective start can be made.

*This paragraph is intended to emphasize the universal applicability of the project under consideration. I am also interested in having it on the record so that I may calibrate my own optimism some years in the future.

STANFORD SPECIAL COLLECTIONS & UNIVERSITY ARCHIVES

STRONG LANGUAGE: In 1952, Shockley sent a forcefully worded memo to Mervin Kelly, president of Bell Labs, arguing for a high-priority effort to create an "automatic trainable robot." Kelly refused, precipitating Shockley's departure from the labs.

not just "semiskilled" industrial workers but also domestic workers in the home.

"A trainable robot will comprise 'hands,' 'sensory organs,' a 'memory,' and a 'brain,' " Shockley wrote. First would be the "robot eye" that Shockley was about to patent. He added that he had "several ideas" for a "courageous direct attack on sense of touch devices…that can recognize parts and their orientation by feel." That is, Shockley would give his robots first sight and then touch. Presumably, the memory, brain, and other senses would follow. Like Diebold, Shockley believed the automation revolution was imminent. With his robots, he predicted, "the increase in productivity of the nation might be…doubled in a decade or less."

Shockley filed his robot eye patent application in November 1952, just before his modification agreement with Bell Labs expired. Ten days later, Shockley got his answer from Kelly: Bell Labs would not support the creation of a trainable robot.

Shockley responded with his feet. He soon took a leave from Bell Labs and would never fully return. He spent a year as a visiting professor at Caltech, making connections to the booming electronics, instrumentation, and military aerospace industry in the Los Angeles area. He had serious discussions with a number of firms to establish a transistor company of his own. None of the prospects satisfied. Shockley returned to the Pentagon, where as the director of research for the Weapons Systems Evaluation Group, he weighed in on issues such as how the U.S. military could best fight a nuclear war.

IN DECEMBER 1954, the U.S. Patent Office granted Shockley's patent on the robot eye. Given Bell Labs' rejection of his pet project, it might have seemed a hollow victory, and yet as the next few months showed, Shockley still believed that the robot eye might prove useful for industry.

Right after New Year's in 1955, he received an invitation from Arnold O. Beckman to return to Los Angeles for a gala honoring Shockley and vacuum-tube pioneer Lee De Forest. At the event on 2 February 1955, Shockley was delighted to discover that Beckman—a Ph.D. chemist and prominent high-tech industrialist—was a fellow devotee of automation.

Born in 1900 and 10 years Shockley's senior, Beckman was the son of an Illinois blacksmith. A tinkerer and inventor even as a youth, he'd studied chemistry and chemical engineering at the University of Illinois and went on to get a Ph.D. in physical chemistry at Caltech in 1928. Beckman took a hiatus from his Caltech studies to work at the newly formed Bell Labs, where he learned electronics and assisted in very early work on statistical quality control.

After finishing his doctorate, Beckman joined Caltech's chemistry faculty. In the mid-1930s, he developed a pH meter, which combined chemistry and electronics in a simple, integrated instrument. Produced by a small firm in which he had a stake, Beckman's pH meter was a runaway success. By the end of that decade, Beckman decided to leave his professorship, take control of the instrument firm, and devote himself to exploring the new world of electronic chemical instrumentation.

Through the 1940s Beckman's firm enjoyed a string of other instrument and electronics breakthroughs, including his own invention of a hugely successful helical potentiometer—the Helipot—and his company grew dramatically. Beckman pushed his firm, renamed

Beckman Instruments in 1950, to expand into automatic process control and electronic computers, and he became a devotee of automation and the automatic factory. His first report to shareholders, in October 1952, began with the slogan "Machines liberate men."

Beckman's pursuit of automation proved lucrative. By the end of 1954, sales had more than doubled, as had the value of the stock; profit approached $1 million, and the number of employees climbed to 1750. Caltech elected Beckman to its board of trustees, the first of its alumni so honored.

At their meeting at the Los Angeles gala in 1955, Beckman and Shockley were much impressed with each other. Both had science Ph.D.s from top schools, had studied at Caltech, had worked at Bell Labs, and possessed high-level security clearances. Each had era-marking inventions to his credit: Shockley, with his role in the first transistor and his conception of the junction transistor, had provided the foundation of the transistor industry, while Beckman, with his pH meter and ultraviolet spectrophotometer, had inaugurated the modern analytical instrument industry.

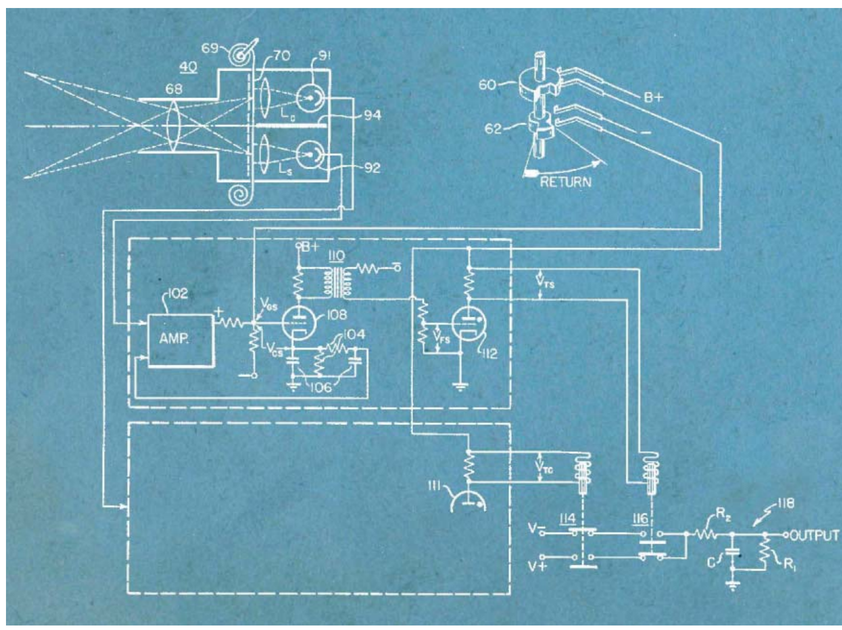
At the gala, Shockley promised to send Beckman his newly issued patent on the robot eye, which Beckman agreed to evaluate for possible use in his company's automation efforts. This promise started a conversation that led, seven months later, to the two men signing a contract to create the Shockley Semiconductor Laboratory of Beckman Instruments Inc.

SHORTLY AFTER THE GALA, Shockley sent Beckman a copy of the patent, asking for "any reactions you have about its potential usefulness." Beckman, though, was focused on several corporate acquisitions and his company's expansion into Europe. He sat on Shockley's patent for nearly two months before passing it along to Jack Bishop, his right-hand man, asking for "R&D comments."

Bishop in turn handed the patent to a trusted engineer, who returned a rapid and negative evaluation: "This system appears to me to be primarily of academic interest and... should not be given serious consideration at this time." The engineer thought that in an industrial application, there would be easier and cheaper approaches than Shockley's and that despite "the fact that the ideas are good," a competitor could easily circumvent Shockley's patent. It made no business sense, in other words. The engineer's report made its way to Beckman, who held onto the R&D evaluation for another month and a half.

Finally, in mid-May 1955, Beckman responded to Shockley. Addressing Shockley as "Bill" and signing as "Arnold," he informed the physicist that his engineering group had examined the patent for use in current or upcoming projects but that "it appears that there are no projects at this time." His closing softened the blow a little: "It was a pleasure to see you again and I hope that our paths may cross frequently."

At the end of July, Shockley called Beckman. He told Beckman about his desire to start a new company and made a new pitch: to take the chemical techniques for making silicon transistors recently created at Bell Labs and bring these new "diffused" silicon transistors to market. What's more, he would develop automated means for the mass production of the transistors. Unlike his reaction to Shockley's robot eye, Beckman's response this time was immediate and enthusiastic: He asked Shockley to meet with him without delay. Two weeks later, on a Saturday, the two sat down for serious discussions.



ROBOT VISION: Shockley's design for an electro-optical control system was, he believed, a critical component for creating trainable robots that could replace human workers.

Even as he awaited Beckman's reply, Shockley was busy. During those months, he considered and then rejected an offer from Howard Hughes to lead a new consolidated semiconductor electronics organization at Hughes Aircraft. Shockley similarly explored then turned down offers to join the physics departments of the University of California, Berkeley, and Yale. All of these offers were extremely prestigious and lucrative. Yet they were also fundamentally conventional. Shockley sought a more radical change for himself. By June 1955, at the age of 45, he decided to leave Bell Labs, resign from his high-level Pentagon job, and exit his marriage. He wanted a new life and a company of his own through which he would be the primary beneficiary of his ideas.

Beckman was most likely attracted to Shockley's new pitch for its fit with his overarching automation strategy. The high temperatures, strong vibrations, and caustic environments of chemical plants and petroleum refineries posed severe challenges for the vacuum-tube electronics then used in sensors and instruments. Rugged and reliable silicon transistors would therefore be invaluable for adapting Beckman's electronic instruments to the control and monitoring of industrial processes. The U.S. military was also very interested in silicon transistors for their ruggedness and reliability.

After the meeting, it took Beckman and Shockley just a few weeks to hammer out a deal. In early September 1955, they signed an agreement creating the Shockley Semiconductor Lab. The agreement stipulated that the lab would remain a part of Beckman Instruments for two years, during which Shockley would have unfettered freedom to pursue new inventions in electronics. But the lab's first activity, the two men agreed, would be the automated manufacture of diffused silicon transistors. Shockley insisted that Beckman give the effort his personal attention and that Beckman Instruments provide the lab with business, administrative, marketing, and sales support. After two years, Beckman would decide whether or not to make the lab into a separate company in which he and Shockley would have large equity stakes.

Shockley spent the fall of 1955 setting up his new lab. Although Beckman's company was headquartered in Southern California, Shockley convinced him to locate the lab near Palo Alto, Calif. Shockley had grown up in Palo Alto, and his mother still lived there. Stanford University was nearby, and the area had a vibrant scene in electron-tube production for military and commercial markets, as well as nascent aerospace activities. San Francisco just to the north was a financial, military, commercial, and cultural center. And the weather was excellent.

Shockley drafted a press release to announce his new laboratory. It reveals his desire to assemble a team of virtuosi for semiconductor innovation and, in doing so, to give birth to a semiconductor community on the San Francisco Peninsula. "The opportunity to contribute to the growth of a new electronics community will attract men of imagination and initiative along both social and technological lines," he wrote. "I hope to create a vehicle in which such men can make their maximum contributions and find their greatest satisfactions and rewards." Though it's unclear if the press release was ever made public, Shockley's aspirations resonate with the image that Silicon Valley later attained.

SHOCKLEY ASSEMBLED A TEAM of "men of imagination and initiative," including Gordon Moore, Robert Noyce, Jean Hoerni, Eugene Kleiner, and Jay Last. Then, in late 1956, Shockley shared the Nobel Prize in physics for his role in establishing transistor electronics. Despite these successes, Shockley's lab soon shattered.

Shockley's competitive streak and capricious management style were unfettered. He decided to abandon the diffused silicon transistor in favor of an invention of his own, the four-layer diode. The young researchers, including Moore and Noyce, became deeply concerned and dissatisfied, and they appealed to Beckman for help. They told Beckman that they still wanted Shockley as an adviser but that they needed a real manager. In the end, after getting assurances from Shockley and his friends in Bell Labs' top brass that Shockley's direction was essentially sound, Beckman stayed the course: Shockley would continue to lead the lab.

microprocessors, Intel eventually became the world's largest semiconductor company.

Seen in this light, Shockley Semiconductor was incredibly productive. But for its founders, Beckman and Shockley, the lab was a failure. It never produced a silicon transistor and found few takers for the four-layer diode. Finally, in 1960, Beckman sold the operation, and it closed several years later. Shockley retreated to a professorship at Stanford, and Beckman would forever regret that he had not retained as his employees the dissidents who founded Fairchild and Intel.

HUMBLE START: The Shockley Semiconductor Laboratory of Beckman Instruments was housed in an old Quonset hut at 391 San Antonio Road in Mountain View, Calif. It was the first silicon electronics lab of what would become Silicon Valley.

In response, at the end of 1957, Moore, Noyce, and six others quit and created a new company, Fairchild Semiconductor, just a couple of kilometers away. In Silicon Valley's first silicon electronics spin-off, the "traitorous eight" (as Shockley reputedly called them) focused on making the diffused silicon transistor that Shockley had abandoned. They succeeded within a year and over the next several years introduced important new transistors and integrated circuits based on the "planar process," a breakthrough manufacturing technology that allowed circuits to be chemically printed in silicon substrates. As planar silicon transistors and microchips replaced vacuum tubes, "electronics" and "semiconductor electronics" became increasingly synonymous.

From the 1960s into the 1980s, further spin-offs from Fairchild and related start-ups in semiconductor equipment and materials populated the San Francisco Peninsula. Counting the spin-offs of these spin-offs, Fairchild's descendants numbered in the hundreds. In 1968, Moore and Noyce created one of these "Fairchildren": Intel Corp. First pioneering memory chips and then

Until his death in 1989, Shockley never returned to his grand vision of the trainable robot, even as others made industrial robotics real. In the late 1950s, George C. Devol started the robotics company Unimation, whose transistorized robotic arm, the Unimate, entered service in the early 1960s to move hot metal castings in a General Motors plant. Similar programmable robotic arms proliferated during the 1970s, as improvements in microchips made computing power more affordable. Then, in the 1980s, robust machine vision–successor to Shockley's "eye"–was added to these robotic arms.

The progression of robotics continues, to the point where household robots, weaponized drones, intensely automated factories, and self-driving cars now seem almost commonplace. In the end, Shockley did prove instrumental in the realization of the robots he had imagined, but not in the way that he had hoped. The microchip industry that emerged, in part, from Shockley's lab enabled the rise of robotics, but he himself played no role in the robotics revolution. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/shockleyrobot1213

AUSTRALIA'S (LESS SUPER) SUPER-HIGHWAY

The rise and fall of the most ambitious broadband fiber project ever

BY **RODNEY S. TUCKER**

In April 2009, Australia's then prime minister, Kevin Rudd, dropped a bombshell on the press and the global technology community: His social democrat Labor administration was going to deliver broadband Internet to every single resident of Australia. It was an audacious goal, not least of all because Australia is one of the most sparsely populated countries on Earth.

The National Broadband Network (NBN), as the project is known, would extend high-speed optical fiber directly into the homes, schools, and workplaces of 93 percent of Australians. The remaining 7 percent, living out of fiber's reach in rural areas and remote pockets of the vast outback in the middle of the continent, would be linked to the Internet via state-of-the-art wireless and satellite technology.

Governments and telecom carriers in other countries, such as Japan, New Zealand, Singapore, and South Korea, have similarly embarked on endeavors to deploy widespread fiber-to-the-premises (FTTP) networks. But those countries are much smaller and more densely populated than Australia. The country has roughly the landmass of the contiguous United States but only 7 percent as many people—fewer, in fact, than the state of Texas. To lay a nationwide fiber footprint,

PHOTOGRAPH BY Adam Voorhes

the government would need armies of workers and unprecedented access to rights-of-way, utility poles, and underground ducts.

And indeed, the NBN's estimated cost was high: The latest figure was AU $45.6 billion (US $44.1 billion). It would be one of the largest, most pervasive FTTP rollouts any government has ever attempted. But although the price would be great, so would the impact: The network would bring broadband access to underserved areas, but it would also raise standards of living everywhere by driving innovations in telemedicine, remote education, e-commerce, and e-governance. A government-funded report released this year by Deloitte Access Economics concluded that the NBN would provide job opportunities, time savings, and other benefits worth, on average, AU $3800 (US $3600) per household per year by 2020, when construction would be nearly complete. In addition, fiber's enormous bandwidth capacity means that transmitting and receiving equipment could be upgraded indefinitely at low cost, allowing the NBN to keep pace for decades with the incessant demand for higher data rates.

Yet despite these benefits, some conservative politicians and media outlets vehemently opposed the plan. In the campaign leading up to a national election this September, the fate of the NBN was vigorously debated. Although polls showed that the majority of voters supported the project, they nevertheless rejected the Labor Party and ushered into power an alliance of moderate conservative parties known as the Coalition, whose leader and now prime minister, Tony Abbott, promised to drastically scale back the national network.

So now, after three years of planning and construction, during which workers connected some 210 000 premises (out of an anticipated 13.2 million), Australia's visionary and trailblazing initiative is at a crossroads. The new government plans to deploy fiber only to the premises of new housing developments. For the remaining homes and businesses—about 71 percent—it will bring fiber only as far as curbside cabinets, called nodes. Existing copper-wire pairs will cover the so-called last mile to individual buildings.

Such issues are not unique to Australia. Enthusiasm for near-universal broadband was once widespread, and it is still being pursued in the countries mentioned above, among others. But the ardor has cooled in recent years as legislators in many parts of the world move to cut government spending. Unfortunately, as is so often the case with technology, the public debate is beset by misunderstanding, misinformation, and a general lack of technical knowledge. A rare opportunity for growth and development is about to be lost, and disappointingly few people fully grasp the implications of that loss.

For example, in Australia, the Coalition is pursuing a fiber-to-the-node (FTTN) strategy because it would be much cheaper in the short term—about two-thirds the price of the original NBN. But that calculus overlooks the longer-term realities. Copper links simply lack the capacity to support the massive growth in data consumption that analysts predict. Eventually, Australians will have no choice but to replace those links with fiber, probably before the end of this decade. At that point, upgrading to an FTTP network will add to the cost of the FTTN rollout, increasing the total investment beyond the price of installing that fiber today.

And in delaying the deployment, Australians will have passed up a unique chance to become leaders in the global digital economy—an opportunity they may not get again.

Today in Australia, as in much of Asia, Europe, and North America, commercial carriers own and operate competing landline networks. Such an arrangement normally encourages carriers to stay at the forefront of technology. However, it can have disadvantages as well: In a thinly populated country such as Australia, carriers may cherry-pick customers in the few dense urban centers where they know they can make the most profit. Consequently, progress is slow to reach the vast majority of people living in rural and suburban areas.

It's not surprising, then, that among developed countries, Australia is notable for its paucity of fiber-optic links. The highest rates are in Japan and South Korea, densely populated countries with small landmasses, where fiber accounts for more than 60 percent of broadband lines. In larger, more sparsely populated countries, such as the United States and Canada, rates are much more modest. In Australia, the rate is less than 2 percent.

Today, more than two in three Australian households have fixed broadband subscriptions. Most of those connections still use digital subscriber line (DSL) technology, which transmits data packets at higher frequencies than do analog voice signals, enabling Internet traffic to travel over telephone lines at relatively high bit rates. In a DSL system, twisted copper pairs, also known as loops, connect each customer to a central switching office. There, a rack of modems known as DSL access multiplexers, or DSLAMs, link the local loop to the backbone networks of various Internet service providers.

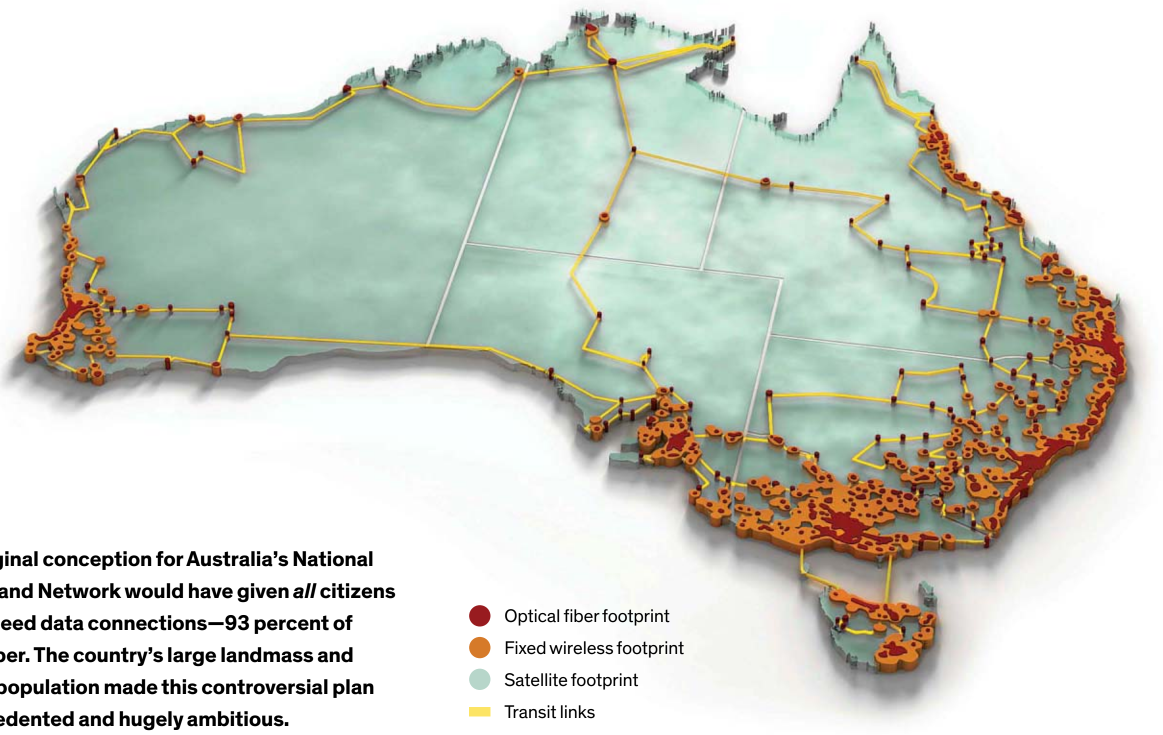
The problem with relying on DSL for broadband service is that many modern applications, including ultrahigh-definition videoconferencing and 3-D television, already require faster transmission speeds than these lines can provide. The biggest bottleneck is the copper itself. Due to the electrical properties of the metal, signals distort and weaken considerably with distance and can interfere with signals traveling through neighboring wires. This severely limits the bit rate of connections, particularly long ones. While customers close to a central office can receive rates as high as 24 megabits per second (using a common standard known as ADSL 2+), more distant customers experience much slower speeds. In Australia, where loops can be quite long and where some users opt for low-speed plans, the average Internet connection is just 4.8 Mb/s. And because the upload rate for DSL rarely exceeds more than one-fourth the download rate, the service doesn't work well for high-bandwidth two-way applications such as videoconferencing.

AUSTRALIA IN THE SLOW LANE

Global ranking		Average connection speed (Mb/s)
1	South Korea	13.3
2	Japan	12.0
3	Switzerland	11.0
4	Hong Kong	10.8
5	Latvia	10.6
6	Netherlands	10.1
7	Czech Republic	9.8
8	United States	8.7
9	Sweden	8.4
10	United Kingdom	8.4
45	**Australia**	**4.8**
Global average:		3.3 Mb/s

SOURCE: AKAMAI TECHNOLOGIES

BROADBAND FAR AND WIDE



The original conception for Australia's National Broadband Network would have given *all* citizens high-speed data connections—93 percent of them fiber. The country's large landmass and sparse population made this controversial plan unprecedented and hugely ambitious.

SOURCE: NBN CO

The leaders of the Labor Party weren't the first Australians to recognize the need for a faster, more inclusive network. Telecom carriers and federal advisory groups have been kicking around proposals for a national broadband network since about 2003. But it wasn't until December 2007, after the Labor Party won majority power, that the government committed to the venture.

At first, Labor representatives thought the new network should use an FTTN architecture, which would require removing DSLAMs from central offices, located kilometers from customers, and installing new ones in nodes as close as a couple of hundred meters. The nodes would connect to the central offices via fiber and relay data to and from each customer's premises using very-high-bit-rate DSL, or VDSL, the highest-speed DSL standard available at the time. These shorter copper loops would boost average speeds considerably–to as high as 50 Mb/s, depending on the distance between the node and the premises. The resulting FTTN network wouldn't be nearly as fast as a full-blown FTTP grid, but the anticipated cost seemed more reasonable.

The government also assumed that the best way to build the network was to award the job to a commercial carrier through a bidding process. It would grant the winner a monopoly license and pitch in AU $4.7 billion to subsidize the cost of construction. Six carriers, including the market leader Telstra, submitted proposals by November 2008. To evaluate them, the government appointed an expert panel; I was among its seven members.

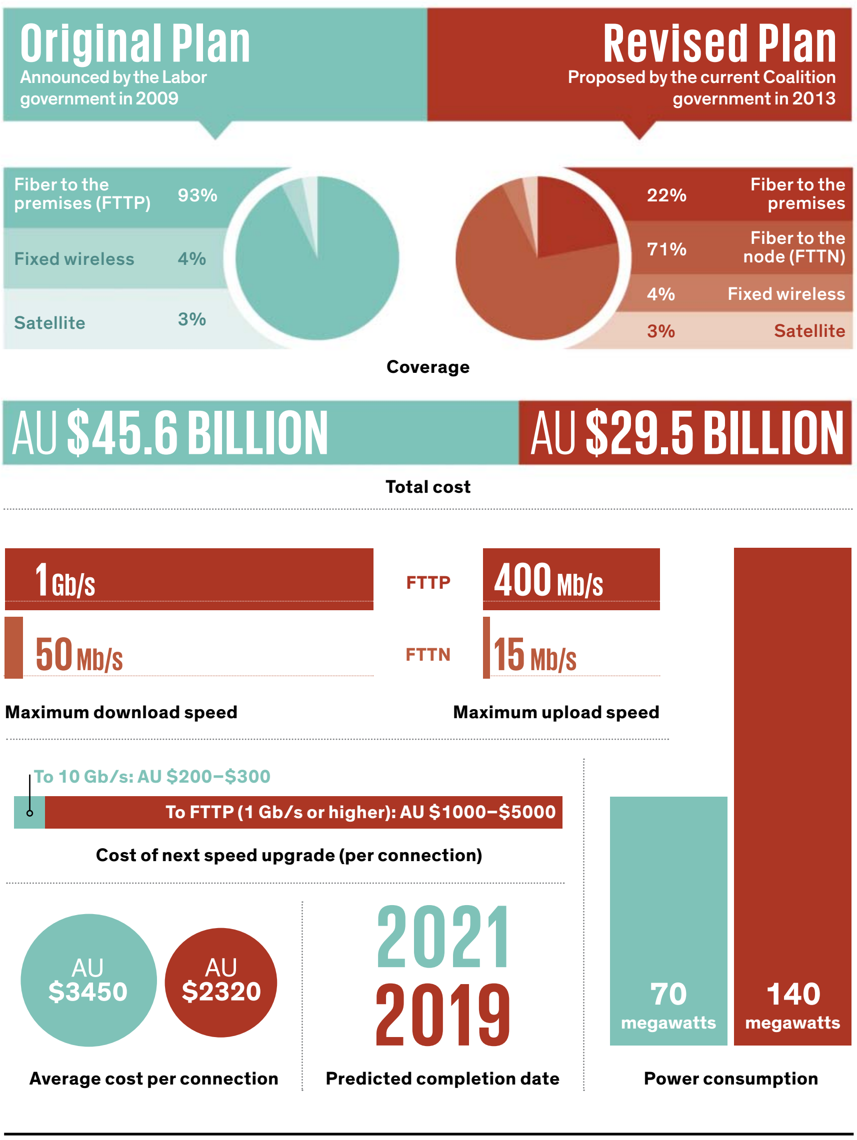
After studying the proposals, we agreed on two key points. First, we found that the global economic recession, sparked by the bursting of the U.S. housing bubble in 2006, was preventing Australia's carriers from raising enough capital to fully fund the construction of a national network. In fact, none of the bidders came up with a viable business model. It was clear that unless the government bankrolled the majority of the cost, a commercial network would not likely succeed.

Our second observation was that an FTTN layout would be a bad idea. Using VDSL, a home connection could theoretically deliver 50 Mb/s, but only if the node sat very close to the house–a mere 100 meters or so away. Since the panel disbanded, a newer standard, VDSL2, has emerged. When combined with a novel interference-reduction technique called vectoring, it can provide download speeds up to about 100 Mb/s over short distances. And now an even faster standard known as G.fast is in the works, which promises download rates up to 1 Gb/s, but again, only for very short connections. For customers on longer loops, telecoms would be able to guarantee only about 50 Mb/s.

Market analysts project that data usage from a single family or small business could easily surpass that rate by 2020, and to meet this demand, Australia would need an FTTP network. Laying a cheaper FTTN footprint first would make little sense because it's not a necessary step toward realizing an all-fiber system. In fact, an FTTN network requires special equipment and infrastructure, including nodes, that would have to be removed and discarded

ILLUSTRATION BY Emily Cooper

TWO FACES OF THE NBN



SOURCES: NBN CO; COALITION'S NBN POLICY STATEMENTS; "ENERGY CONSUMPTION IN ACCESS NETWORKS," J. BALIGA, R.S. TUCKER, ET AL., OPTICAL FIBER COMMUNICATION/NATIONAL FIBER OPTIC ENGINEERS CONFERENCE, 2008

during an FTTP upgrade. An interim FTTN rollout would consequently end up costing Australians more in the long term than simply investing in FTTP technology today.

For these and other reasons, we recommended that the government itself create a national FTTP network. Incredibly, it accepted our advice.

In April 2009, following Prime Minister Rudd's landmark announcement, the Australian government established NBN Co to build and operate the future National Broadband Network. The government-owned company would be responsible for connecting every home and business to more than 100 hubs, called points of interconnect, around the nation. These are places where commercial Internet providers and other content-delivery companies, called retail service providers, would hook into the network. To reduce some of the cost of laying fiber lines, NBN Co would pay commercial carriers to access existing underground ducts and pits and decommission copper telephone lines and DSLAM equipment. Telstra currently owns the vast majority of this infrastructure, and the government had agreed to pay AU $11 billion to access it.

As the sole owner of the new national network, NBN Co would run what's known as a Layer 2 network. It would offer commercial providers a choice of speeds at set prices (from AU $24 per month for 12 Mb/s downloads and 1 Mb/s uploads to AU $150 per month for 1 Gb/s downloads and 400 Mb/s uploads). It would route the data to and from the providers' customers using Ethernet protocol. The providers would add on the remaining layers, including data packaging, encryption, and error correction, and bill customers directly. Although NBN Co alone would manage the physical infrastructure, including the modems in people's homes, providers could still compete, based on the type of content they offered and the quality of their service.

To construct the network's fiber web, engineers opted to use passive optical network (PON) technology, a standard approach for FTTP networks. In NBN Co's PON system, a single fiber would ferry data from a central office to a small curbside cabinet, where a beam splitter would divide the signal, guiding the light through up to 32 branching fibers, each leading to a separate premises. Unlike active optical networks, which electronically switch data at the cabinet in order to route it to its final destination, PON systems broadcast to all premises on a splitter. They rely on electronic switches at each customer's terminal to weed out the neighbors' traffic and encrypt the data to prevent eavesdropping. PON systems also tend to be cheaper, use less power, and are easier to maintain than active ones because they don't require engineers to install and tend to switching equipment in outdoor cabinets.

When construction began on the NBN in 2010, the fastest equipment available for transmitting data on a PON network relied on an industry standard known as gigabit PON, or GPON, which can send 2.4 gigabits per second to each splitter. This overall capacity would be divided among all of the premises on a splitter. However, if several customers in a neighborhood opted for fast services, NBN Co would simply install more splitters at the cabinet—a quick, 20-minute job. This way, NBN Co could guarantee that every fiber-connected Australian who wanted the maximum 1 Gb/s rate could get it.

Inevitably, though, some people would fall outside this fiber footprint. About 7 percent of Australians live in rural communities or remote outposts where wired broadband access is technically or economically unviable. NBN Co would connect about half this population via fixed wireless towers equipped with standard 4G LTE technologies capable of delivering download speeds up to 25 Mb/s and upload speeds up to 5 Mb/s to each customer. The other half would be served by two new high-bandwidth geostationary satellites due to launch in 2015, which would provide similar data rates.

But no matter the type of access technology—fiber, wireless, or satellite—NBN Co would still charge commercial providers the same wholesale rates to use its pipes, ensuring equal and fair prices to all consumers regardless of location.

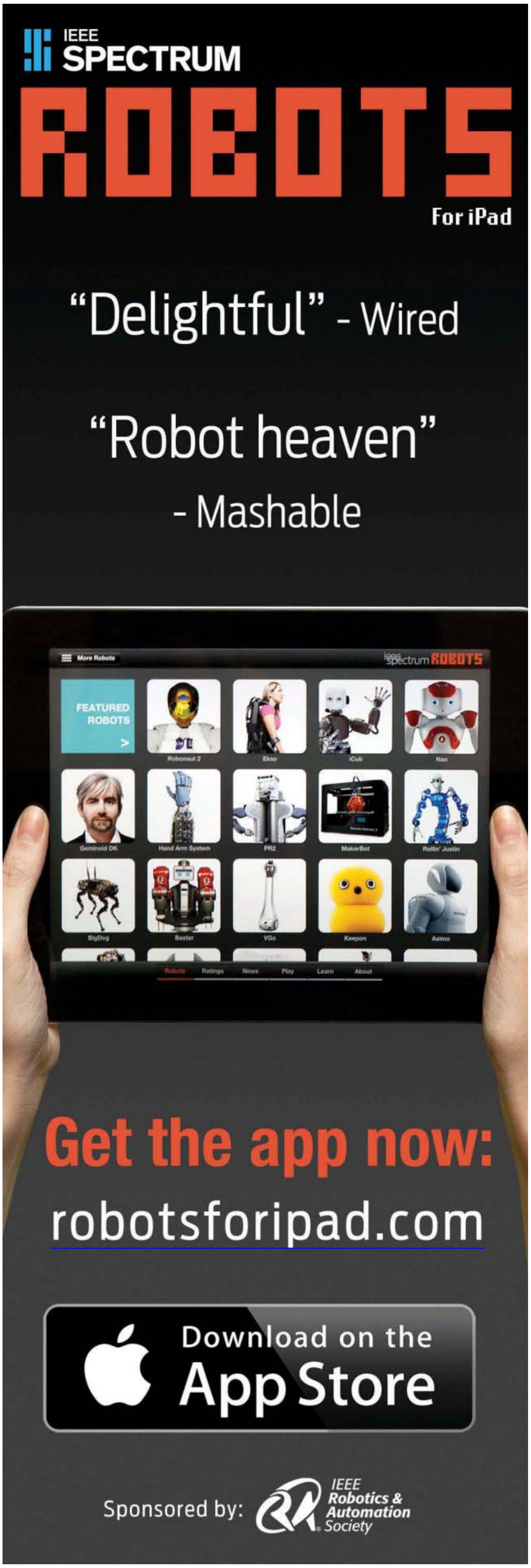
Many politicians and industry executives praised the NBN plan. Alan Noble, Google Australia's head of engineering, called it "the greatest enabler of innovation." Others said it was "a critical part in the evolution of the Internet" and "too good an opportunity to miss." Nevertheless, the plan was controversial from the outset. Members of the conservative Coalition, concerned about rising costs and construction delays, have described the NBN as a "dangerous delusion," a "white elephant on a massive scale," and a "shockingly misconceived, wasteful exercise in public policy."

Some of the early criticisms, particularly from media commentators, stemmed from technical misunderstandings. Opponents of the FTTP approach, for instance, often reasoned that the popularity of mobile gadgets is causing wireless technologies to advance so rapidly that they will eventually offer greater speeds than fiber, making the NBN obsolete.

The fallacy of this assumption is immediately apparent to anybody with a basic knowledge of wireless networks. Such connections will always be limited by the bandwidth capacity of a cellular base station, which must be shared among all its users. Even if one station could use all available radio spectrum to serve one customer, the bandwidth of frequencies that can be passed through an optical fiber would still be some 20 000 times as great.

What's more, mobile systems may not be able to sustain their awesome growth without an extensive fiber network. Already, operators are deploying miniature base stations known as small cells in homes, businesses, and busy urban centers, to help expand capacity and bring services to places where traditional towers may not reach, such as indoors. The glut of data flowing through these cells will need to be hauled to and from an operator's core network—a job that suits fiber very well.

Other critics of the Labor Party's plan worried that giving NBN Co sole ownership of Australia's physical network would stifle infra-



structure competition, keeping prices high for consumers and slowing the adoption of new network technologies. This argument might be persuasive in more densely populated countries such as the United States, where high consumer demand usually ensures vigorous competition based largely on technology. Indeed, in the United States, Verizon began offering its FiOS FTTP service in 2005, and plans are now available to more than 18 million homes, 5 million of which have subscriptions, the company says.

But in Australia, providers have already demonstrated that a free market hasn't produced good access options for most consumers. In the 1990s, for instance, Telstra and its competitor Optus strung separate hybrid fiber-coaxial lines, a faster service than DSL, to the *same* 2 million premises in some populous suburbs of Sydney and Melbourne. Meanwhile, millions more premises missed out on the upgrade.

By far the biggest concern about the FTTP model was, and still is, that the benefits won't justify its high cost. The Coalition argues that an FTTN network, though less than ideal, would provide more value per dollar. But the numbers just don't add up.

An FTTP network offering peak speeds of up to 1 Gb/s would have cost Australians about AU $3450 per premises, according to NBN Co's cost analysis. By contrast, the new Coalition government estimates that each FTTN connection, capable of guaranteeing up to 50 Mb/s, will cost on average around AU $2320—a whopping two-thirds the cost of a vastly superior FTTP link. And if consumer data rates continue to climb as fast as analysts predict, many FTTN customers will probably want to upgrade to FTTP technology before 2020. To accommodate them, the Coalition government plans to offer "fiber-on-demand" service, in which a customer could choose to pay out of pocket for installing fiber from a curbside node to a home or business. These upgrades would likely add another AU $1000 to $5000 to the price of each connection, depending on the length of the fiber and the amount of labor required.

In the meantime, an FTTP network using GPON infrastructure could last well into the future. Upgrading it to the next-generation standard, called XGPON, which will support up to 10 Gb/s, would simply require replacing some of the equipment in central offices and the terminal modem at each customer's premises—for a likely total bill of no more than AU $300 per connection. In the future, newer standards could provide even faster bit rates for a comparable cost.

It has been painful watching the formation of this "futureproof" network come to an end. I can't help but think of the United States' Interstate Highway System, championed by President Dwight D. Eisenhower in the 1950s, which paved the way, literally, for a booming transportation-based economy. In Australia, a fiber-based broadband highway could transform the country's digital economy in much the same way.

Sadly, the new Coalition government seems impervious to these arguments and is determined to downscale the NBN. I am left clinging to the hope that Australians will realize the foolishness of abandoning the FTTP network and insist that their leaders reconsider or devise a new plan that's not too far removed from the Labor Party's revolutionary vision. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/australianbn1213

FACULTY POSITIONS IN COMPUTER SCIENCE

جامعة الملك عبدالله للعلوم والتقنية
King Abdullah University of Science and Technology

The Computer Science Program in the Computer, Electrical, and Mathematical Sciences and Engineering Division at King Abdullah University of Science and Technology (KAUST) invites applications for faculty positions at all ranks (Assistant, Associate, and Full Professors).

KAUST is an international, graduate research university dedicated to advancing science and technology through interdisciplinary research, education, and innovation. Located on the shores of the Red Sea in Saudi Arabia, KAUST offers superb research facilities, and internationally competitive salaries. The university attracts top international faculty and students to conduct fundamental and goal-oriented research to address the world's pressing scientific and technological challenges.

Areas of interest are:

- Artificial Intelligence
- Data Management and Big Data: Storing, indexing and querying very large datasets using large parallel and distributed computing systems; mining and knowledge extraction from very large data
- Large Scale Data Mining and Knowledge Extraction
- Parallel and Distributed Systems
- Visual Computing (including but not limited to Visualization and Physics-based simulation)
- Bioinformatics and all related subfields (e.g. Computational Genomics, Synthetic Biology, Biological Networks)
- High Performance Computing
- Operating Systems

Further information can be obtained by visiting **http://apptrkr.com/399011**
Applicants should have a proven track record, relevant PhD degree, as well as the ability to establish a high impact research program and demonstrate commitment to teaching at the graduate level.

How to Apply:
You will be required to complete a brief application form and upload a single PDF file including:

- Complete curriculum vitae with a list of publications
- Research plan
- Statement of teaching interests
- Names and contact information for at least three references for an Assistant Professor position
- List with the names and affiliation of potential referees for Associate Professor and Full Professor positions

Applications received by **January 15, 2014** will receive full consideration and positions will remain open until filled.

ELECTRICAL ENGINEERING AND COMPUTER SCIENCE
UNIVERSITY of MICHIGAN ■ COLLEGE of ENGINEERING

Electrical and Computer Engineering
University of Michigan, Ann Arbor

The Electrical and Computer Engineering (ECE) Division of the Electrical Engineering and Computer Science Department at the University of Michigan, Ann Arbor invites applications for junior or senior faculty positions, especially from women and underrepresented minorities. Successful candidates will have a relevant doctorate or equivalent experience and an outstanding record of achievement and impactful research in academics, industry and/or at national laboratories. They will have a strong record or commitment to teaching at undergraduate and graduate levels, to providing service to the university and profession and to broadening the intellectual diversity of the ECE Division. Although the research areas of particular interest are networks and communications, computer vision, integrated circuits and optics, applications are welcome in all relevant areas of research.

The highly ranked ECE Division (**www.eecs.umich.edu/ece**) prides itself on the mentoring of junior faculty toward successful careers. Ann Arbor is often rated as a family friendly best-place-to-live.

Please see application instructions at **www.eecs.umich.edu/eecs/jobs**

Applications will be considered as they are received. However, for full consideration applications must be received by December 8, 2013.

The University of Michigan is an Affirmative Action, Equal Opportunity Employer with an Active Dual-Career Assistance Program. The College of Engineering is especially interested in candidates who contribute, through their research, teaching, and/or service, to the diversity and excellence of the academic community.

UNIVERSITE Concordia UNIVERSITY

STRATEGIC HIRING POSITION
ENGINEERING FOR SYNTHETIC BIOLOGY

CONCORDIA.CA

Concordia University, Montreal, Canada. The Faculty of Engineering and Computer Science is seeking excellent tenure-track candidates at the Assistant or Associate Professor ranks in the area of Engineering for Synthetic Biology. This successful applicant will become a member of one of the following departments, depending on his or her background: Electrical and Computer Engineering, or Mechanical and Industrial Engineering. Applicants must possess expertise and research interests in an area of research and scholarship of benefit to Synthetic Biology such as, but not limited to:

- genetic signal & information processing devices & systems;
- biological nanotechnology & microsystems;
- miniaturized bio-medical instrumentation;
- hybrid bio-electro-mechanical systems.

Applicants must hold a PhD degree in a relevant engineering discipline. The language of instruction at Concordia is English; however, knowledge of French is an asset. Detailed applications should include a CV, teaching and research statements, and names of three referees, and shall be accepted in electronic form (PDF) until positions are filled. Applications should be sent **no later than January 15, 2014**, to **Dr. Rama Bhat, Associate Dean for Academic Affairs**, at rama.bhat@concordia.ca. Further details on these positions are available at **encs.concordia.ca**. All qualified candidates are encouraged to apply; however, Canadian citizens and permanent residents of Canada will be given priority. Concordia University is committed to employment equity.

FACULTY SEARCH

ShanghaiTech University

School of Information Science and Technology

The School of Information Science and Technology (SIST) in the new ShanghaiTech University invites applications to fill multiple tenure-track and tenured positions. Candidates should have an exceptional academic record or strong potential in frontier areas of information sciences.

ShanghaiTech is founded as a world-class research university for training future scientists, entrepreneurs, and technology leaders. Besides keeping a strong research profile, successful candidates should also contribute to undergraduate and graduate education within SIST.

Compensation and Benefits:
Salary and startup fund are highly competitive, commensurate with academic experience and accomplishment. ShanghaiTech also offers a comprehensive benefit package which includes housing. All regular faculty members are hired within ShanghaiTech's new tenure-track system commensurate with international practice and standards.

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

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

Applications:
Submit (all in English) *a cover letter, a 2-page research plan, a CV including copies of 3 most significant publications, and names of three referees* to: **sist@shanghaitech.edu.cn**.

Deadline: December 31th, 2013 (or until positions are filled). We have 10 positions for this round of faculty recruitment.

For more information, visit http://www.shanghaitech.edu.cn.

South University of Science and Technology, Shenzhen, China

Faculty position in Electronic Engineering

The Department of Electronic Engineering at the South University of Science and Technology invites applications for faculty positions at all ranks of tenured and tenure-track faculty members in all areas of electrical and electronic engineering. In particular, we are in high demand of applicants in the area of microelectronics, including IC design and Device Process/Technology, Micro/Nano-Electro-Mechanical Systems, Photonic Integrated Circuits, 3D Integration and Packaging, Testing and Reliabilities, Thin Film Transistors and Displays etc. Applicants should have a PhD with demonstrated strength in research and a commitment to teaching. Successful candidates are expected to pursue an active research program, to teach both graduate and undergraduate courses, and to supervise graduate students.

South University of Science and Technology, officially established in April 2012, is a research-intensive public institution funded by the municipal of Shenzhen, a growing international metropolitan neighboring Hong Kong. The University is accredited by the Ministry of Education, China and is a pioneer in higher education reform in China. The teaching language at the University is English or Putonghua. The choice is made by the instructor.

The University offers internationally competitive salaries, fringe benefits including medical/dental insurance, retirement and housing subsidies.

Applications including full curriculum vitae, list of publications, statement of research, and names of five referees addressed to Professor Yu Hong Yu, and should be sent by email to **ecesearch@sustc.edu.cn** as well as **hiring@sustc.edu.cn**.

Additional information is available at **http://www.sustc.edu.cn** and **http://english.sina.com/china/2012/0902/502496.html**.

THE UNIVERSITY OF TEXAS AT AUSTIN
Electrical and Computer Engineering

ECE Faculty Searches

The Department of Electrical and Computer Engineering at The University of Texas at Austin invites applications for the following tenure-track and tenured faculty positions:

Dula D. Cockrell Centennial Chair in Engineering

The Department of Electrical and Computer Engineering at The University of Texas at Austin invites applications for the Dula D. Cockrell Centennial Chair in Engineering in microelectronics, with preference given to nanoscale technology, science and manufacturing, for applications in energy, cloud and mobile computing, biology, health care, integrated man-machine interfaces, or related areas. Candidates should have an internationally recognized record of research and scholarship, and possess the qualities necessary for academic leadership. The successful applicant will be expected to supervise graduate students, teach undergraduate and graduate classes, and be involved in service to the university and profession. This appointment offers outstanding scope for the appointee's individual and collaborative research talents and provides an opportunity for leadership in developing sponsored research programs. Applicants for this tenured position should have an earned PhD in electrical engineering or a related discipline.

Silicon Laboratories Endowed Chair in Electrical Engineering

The Department of Electrical and Computer Engineering at The University of Texas at Austin invites applications for the Silicon Laboratories Endowed Chair in Electrical Engineering in mixed-signal/analog design, CMOS sensors and related areas. Candidates should have an internationally recognized record of research and scholarship, and possess the qualities necessary for academic leadership. The successful applicant will be expected to supervise graduate students, teach undergraduate and graduate classes, and be involved in service to the university and profession. This appointment offers outstanding scope for the appointee's individual and collaborative research talents and provides an opportunity for leadership in developing sponsored research programs in mixed-signal/analog design. Applicants for this tenured position should have an earned PhD in electrical engineering or a related discipline.

Tenure-Track Faculty Positions

The Department of Electrical and Computer Engineering at The University of Texas at Austin has two faculty openings at the assistant professor level with start date of Fall 2014. Position 1: Exceptional candidates in any area of electrical and computer engineering will be considered. Position 2: Targeted to candidates in the area of systems biology. All applicants should have received or expect to receive a doctoral degree in electrical or computer engineering or related discipline prior to September 2014.

Application Instructions

All applications must be submitted electronically at **https://www.ece.utexas.edu/faculty/openings**. Submit cover letter, current vita, statement of research, and teaching philosophy. For Chair positions, applications should include a minimum of five references who will submit original letters of reference directly to the website. For tenure-track faculty positions, at least three references who will submit original letters of reference should be included.

For Chair positions, applications will be considered until the positions are filled. For tenure-track positions, applications should be submitted by December 31, 2013 to ensure fullest consideration. Earlier submission is strongly encouraged.

The successful candidate will be required to complete an Employment Eligibility Verification form and provide documents to verify identity and eligibility to work in the U.S. A security sensitive background check will be conducted on the applicant selected. The University of Texas at Austin is an Equal Opportunity/Affirmative Action Employer.

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NANYANG TECHNOLOGICAL UNIVERSITY

Rolls-Royce

Professorship/Associate Professorship in Power Electronics

Nanyang Technological University (NTU) in Singapore, a fast-rising global university, is seeking a world-renowned Professor/Associate Professor of Power Electronics for its School of Electrical and Electronic Engineering (EEE). This appointment will be supported by Rolls-Royce plc to develop power electronics technologies for various business sectors.

Young and research-intensive, NTU is ranked 41st in the QS World University Rankings 2013 and 76th in Times Higher Education World University Rankings. For the first time, NTU topped the global rankings for industry income and innovation, making a big jump from last year's 15th place. Well-known for its high academic standards and strong tradition in research, the School of EEE is host to nine mega research centres and more than 50 laboratories, which are well-equipped with modern facilities and state-of-the-art equipment.

Rolls-Royce plc is a world-leading provider of power systems and services for use on land, at sea and in the air. It has a balanced business portfolio with leading positions in the civil and defence aerospace, marine and energy markets. Its global Electrical Power and Control Systems (EPACS) group is supporting the increased electrical requirements from the business through technology development and acquisition.

The ideal candidate is expected to possess an international reputation as a technological leader in this field and a record of distinguished academic and scholarly achievements, along with a demonstrated commitment to the core traditions of excellence and innovation. As a tenured full Professor/Associate Professor, he/she is also expected to provide academic leadership and excellence in the area of power electronics for NTU's School of EEE.

The selected candidate will be expected to work closely with Rolls-Royce in developing capability aligned with the technology needs of the company in the area of power electronics and the use of power electronics in power systems.

Application Procedure:
IMPORTANT -- Please indicate clearly the post applied for (i.e. Professorship/Associate Professorship in Power Electronics when submitting an application or inquiring about this job announcement).

To apply, please refer to the Guidelines for Submitting an Application for Faculty Appointment: **(http://www.ntu.edu.sg/ohr/CareerOpportunities/SubmitanApplication/Pages/FacultyPositions.aspx)** and send your application (cover letter and a full CV) via email to:

Chairman, School Search Committee
c/o Head of Division of Power Engineering
Email: eeehr@ntu.edu.sg

Please ensure that your CV, among other information, also includes the following:
1. A detailed teaching plan and research plan
2. Number of and monetary amount of research grants held at present and in the past
3. Number of Masters and/or PhD students currently supervising/co-supervising
4. Number of Masters and/or PhD students graduated
5. Referees - provide the names, addresses, e-mail addresses and fax numbers of 5 referees

Electronic submission of applications is encouraged. Only short-listed candidates will be notified.

Application Deadline: Position opens until filled

Electrical Engineering Faculty Positions

The Department of Electrical Engineering at The Pennsylvania State University invites applications for a tenure-track faculty position. Applicants at all levels will be considered. Preferred candidates must hold a doctoral degree in Electrical Engineering or a related discipline with appropriate experience. The successful candidate will be expected to establish and sustain an outstanding research program and must have outstanding ability to teach effectively at both the undergraduate and graduate levels.

Technical areas of interest in electrical engineering for this position are in networked systems - ranging from information-theoretic aspects to engineering of components and systems; and in health and life sciences - including biosensors, biomonitoring, and bioinformatics.

To learn more about these positions and the application process please visit the following website: **http://apptrkr.com/403544**. You will be asked to upload a cover letter, resume, research and teaching plans, and the names, e-mail addresses, and telephone numbers of at least four professional references. Employment will require successful completion of background check(s) in accordance with University policies.

Employment will require successful completion of background check(s) in accordance with University policies.

Penn State is committed to affirmative action, equal opportunity and the diversity of its workforce.

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BAYLOR UNIVERSITY

The Electrical and Computer Engineering Department of Baylor University

seeks faculty applicants for three tenured/tenure-track Faculty Positions at all levels and in all areas of electrical and computer engineering. Desired areas of technical expertise include: embedded systems, cyber-physical systems, computer/network security, software engineering, sensor networks, power, and energy. Applicants seeking a senior position must have an impressive record of scholarship and sustained research funding. All applicants must have an earned doctorate and a record of achievement in research and teaching. The ECE department offers B.S., M.S., M.E. and Ph.D. degrees and is rapidly expanding its faculty size. Facilities include the Baylor Research and Innovation Collaborative (BRIC), a newly-established research park minutes from the main campus.

Chartered in 1845 by the Republic of Texas, Baylor University is the oldest university in Texas. Baylor has an enrollment of over 15,000 students and is a member of the Big XII Conference. Baylor's mission is to educate men and women for worldwide leadership and service by integrating academic excellence and Christian commitment within a caring community. The department seeks to hire faculty with an active Christian faith; applicants are encouraged to read about Baylor's vision for the integration of faith and learning at ***www.baylor.edu/profuturis/***.

Application reviews are ongoing and will continue until all positions are filled; however, applications received by January 1, 2014 will be assured of full consideration.

Applications must include: 1) a letter of interest that identifies the applicant's anticipated rank, 2) a complete CV, 3) a statement of teaching and research interests, 4) the names and contact information for at least four professional references.

Additional information is available at ***www.ecs.baylor.edu***. Send materials via email to Dr. Robert J. Marks II at Robert_Marks@baylor.edu. Please combine all submitted material into a single pdf file.

Baylor is a Baptist University affiliated with the Baptist General Convention of Texas. As an Affirmative Action/Equal Employment Opportunity employer, Baylor encourages candidates with an active Christian faith who are minorities, women, veterans, and persons with disabilities to apply.

XJTU–HKUST
Joint School of Sustainable Development
under planning

西安交通大學 XIAN JIAOTONG UNIVERSITY · 香港科技大學 THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Founding Dean

With a vision to advance education and research in sustainable development, The Hong Kong University of Science and Technology (HKUST), in partnership with Xi'an Jiaotong University (XJTU), is establishing the XJTU-HKUST Joint School of Sustainable Development (JSSD). Located in Xi'an of PR China and in close collaboration with HKUST's core operation in Hong Kong, the School will focus on educating a new generation of graduates who are capable of contributing to sustainable development, and on undertaking interdisciplinary high-impact research in energy conservation, resource management and environmental protection. English will be the School's language of instruction and other official conduct.

HKUST is a world-class leading research university and has been ranked overall No. 1 university in Asia for the last two years by QS Asian University Rankings®. XJTU, established in 1896, is in the C9 League, which consists of the top nine prestigious universities in China. The JSSD will have three departments: Sustainable Energy; Sustainable Materials; and Sustainable Systems. Within the next five years, the School is expected to have up to 60 faculty members and an enrollment of more than 1,000 undergraduate and postgraduate students in the three departments.

We are searching for a leading scholar with the vision and capability to be the founding Dean of JSSD. The successful candidate will be a senior academic administrator of HKUST appointed with tenure for posting to the JSSD in Xi'an. The appointee will assume full responsibility for all substantive academic and administrative matters of JSSD, including strategic planning and implementation, organization development, budget planning and control, external publicity, and maintaining relations and linkages with alumni and all relevant parties including governments, institutions and industries. Candidates must meet the high academic and professional standards of the HKUST senior faculty and should possess relevant experience in university administration at the senior level. Proficiency in both English and Chinese is mandatory. Understanding and knowledge of the higher education sector in Hong Kong and the Mainland is essential.

Concurrent with a tenured professorial appointment, the appointment as Dean of JSSD will be for an initial term of five years which is renewable. Remuneration is highly competitive with generous benefits.

Applications/nominations together with a curriculum vitae, a vision statement of the development of the School, and the contacts of at least three referees should be sent to the Chairman of the Search Committee for Dean of JSSD, c/o Human Resources Office, The Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong [email: jssddsrch@ust.hk]. Review of applications/nominations will begin in December 2013 and will continue until the position is filled. For further information about HKUST, XJTU and JSSD, please visit the following websites: HKUST - http://www.ust.hk; XJTU - http://www.xjtu.edu.cn/en/index.html; JSSD - http://www.jssd.ust.hk/en/home.htm

(Information provided by applicants will be used for recruitment and other employment-related purposes.)

Department of Electrical Engineering
University of Minnesota Duluth
Driven to Discover™

Minnesota Power Jack Rowe Endowed Chair in Electrical Engineering

The Department of Electrical Engineering at the University of Minnesota Duluth is seeking candidates for the tenured position of **Jack Rowe Endowed Chair.** The Chair holder is expected to teach courses at both undergraduate and graduate levels, develop an externally funded research program, and establish a strong relationship with communities and industries. A Ph.D. in Electrical Engineering or related field from an accredited institution with a minimum of 10 years of combined research and teaching experience in academia and/or industry is required. The candidates must have a distinguished national and/or international reputation in research with a strong record of obtaining external funding. Experience in working with students, staff, and faculty from diverse communities and cultures is highly desired. Preference will be given to candidates with a background in power/energy or control areas.

To apply online via the Employment System, visit **https://employment.umn.edu/**, and search for Job Requisition 187759 (Minnesota Power Jack Rowe Endowed Chair). Completed applications should include a letter of application, a research plan, a complete resume, and contact information of three professional references.

Applications will be accepted until the position is filled. **University of Minnesota Duluth** is an equal opportunity and affirmative action educator and employer and welcomes applications from women and minorities. For further information, please contact Search Chair Dr. Jiann-Shiou Yang at jyang@d.umn.edu or 218-726-6290.

University of Notre Dame
College of Engineering

Circuits Initiative

The Department of Electrical Engineering and the Department of Computer Science & Engineering at the University of Notre Dame are pleased to announce four new tenured/tenure-track faculty positions in the area of circuits.

Over the last five years Notre Dame has made strategic investments to add faculty and infrastructure in nanoelectronics, wireless communications, advanced diagnostics and therapeutics, and sustainable energy. The opening of Stinson Remick Hall of Engineering in 2010 has provided a wealth of sophisticated lab facilities, including a 10,000-square-foot state-of-the-art clean room. The goal of the circuits initiative is to link major research programs already in place in materials, devices, and systems with innovative research in circuits and future applications.

Candidates at all levels – from assistant professor to full professor with endowed chair – are encouraged to apply. Areas of interest include but are not limited to: circuits based on emerging materials and device technologies (e.g., III-V TFETs, nitride and graphene-based FETs, molecular-scale devices, nano-magnets), self-powered systems, bioelectronics, wireless communications, millimeter-wave technology, and sensors/actuators.

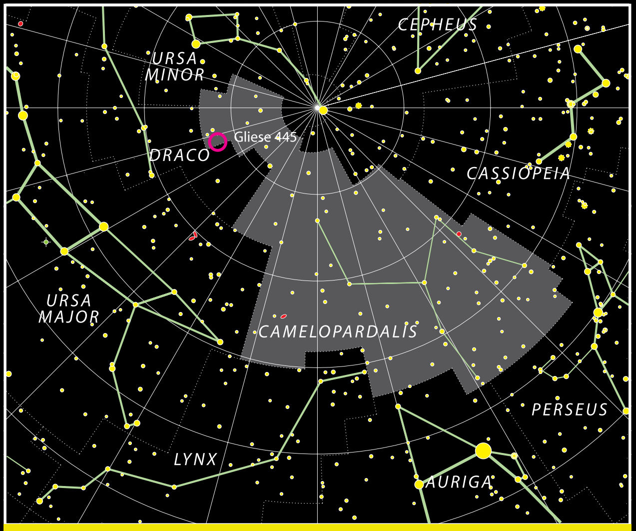
All positions require a Ph.D. in electrical or computer engineering or its equivalent. Those interested can apply on-line at http://ee.nd.edu/apply or by sending a cover letter, CV, and two-page statement of research and teaching interests to: Prof. Tom Fuja, Chair – Department of Electrical Engineering, 275 Fitzpatrick Hall, University of Notre Dame, Notre Dame, IN 46556. (Email: **tfuja@nd.edu**)

The University of Notre Dame is an equal opportunity employer. We particularly invite applications from women and members of groups that are under-represented in science and engineering.

DATAFLOW_

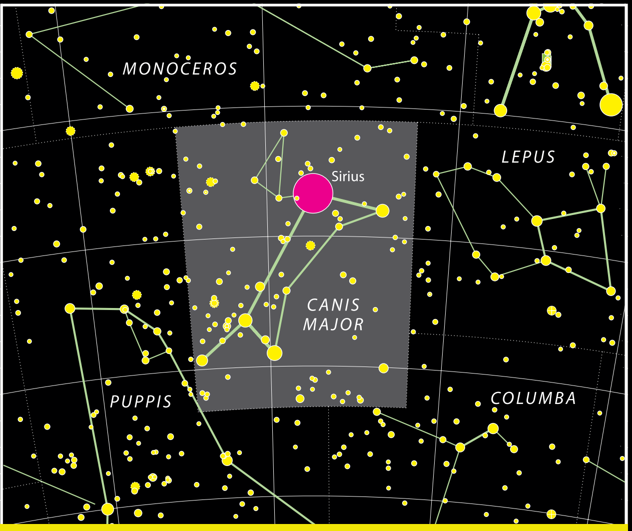
THE STARS THEIR DESTINATION
FOUR INTERSTELLAR PROBES AND THEIR FATES

This past October, NASA announced that after 36 years of flight, Voyager 1 had finally crossed into the interstellar medium that fills the space between the stars. Although it is the first probe to do so, Voyager 1 is not alone in its one-way mission out of the solar system: Four other probes are following it. The destinations of Voyager 1 and 2 and Pioneer 10 and 11 are plotted below. The ultimate destination of the fifth probe—the New Horizons mission to Pluto—is still unknown (its trajectory will be adjusted during its mission in hopes of sending it past another Kuiper Belt object). Although these probes will be dead metal when they reach the stars, all but New Horizons have messages on board designed to be decoded by aliens—just in case. —STEPHEN CASS



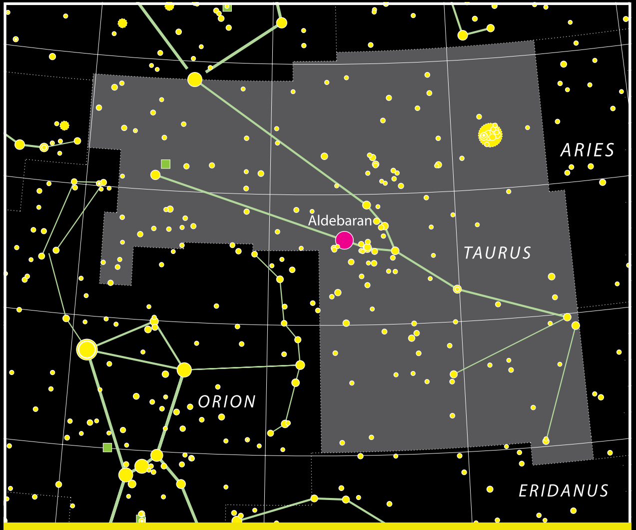
VOYAGER 1: GLIESE 445

A red dwarf 17.6 light-years away, Gliese 445 is currently moving toward us, shortening the distance Voyager 1 must travel. Nonetheless, it will take 40 000 years for the probe to make its closest approach to the star, at a distance of 1.6 light-years.



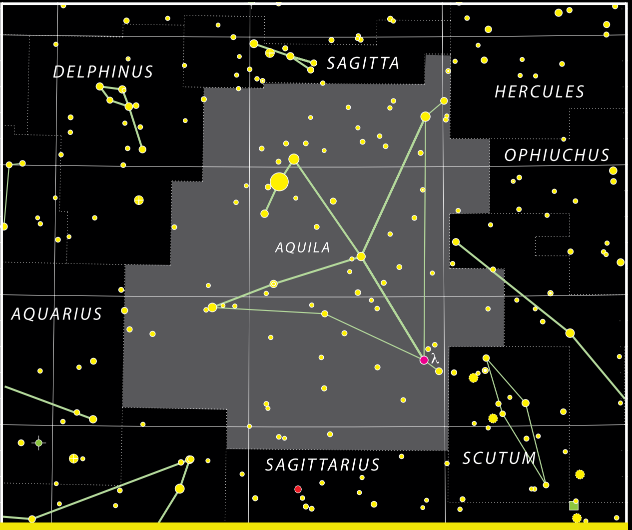
VOYAGER 2: SIRIUS

In about 40 000 years, Voyager 2 will zoom by Ross 248, a dim red dwarf about 10 light-years from the sun. After another 256 000 years, Voyager 2's wanderings will take it in the direction of the brightest star in our sky: Sirius, currently 8.6 light-years away.



PIONEER 10: ALDEBARAN

Pioneer 10, the first probe to visit Jupiter, is now headed in the direction of Aldebaran, a red giant 44 times the diameter of the sun and 68 light-years distant. The probe's closest approach will be in about 2 million years.



PIONEER 11: LAMBDA AQUILAE

Three times the mass of the sun and 55 times as bright, Lambda Aquilae is a young star, only 160 million years old. It will take 4 million years for Pioneer 11 to drift into Lambda Aquilae's neighborhood, 125 light-years away.

ROGER SINNOTT & RICK FIENBERG/SKY & TELESCOPE/INTERNATIONAL ASTRONOMICAL UNION