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An implanted nerve stimulator lets Michael McClellan stand up despite paralyzed legs—and qualifies him to compete in the cyborg Olympics.

TOP TECH 2016

The editors survey thirteen technological developments that you are sure to be hearing a lot more about later in the year. P. 25

On the Cover **Illustration for *IEEE Spectrum* by Thirst**

PHOTOGRAPHS BY **Nathaniel Welch**

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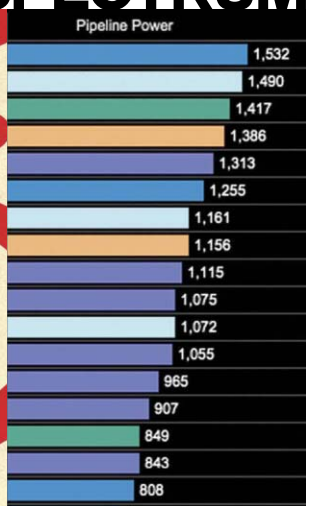

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- **FINDING DISASTER VICTIMS** Researchers at MIT Lincoln Laboratory have developed SAFE, an information-management system that uses data from several social networking sites such as Twitter and Foursquare to identify victims and find missing people in the event of a natural disaster.
- **ALL ABOUT WILDFLOWERS** For those who want to get closer to nature and learn about the plants around them, there's now an app for that. IEEE Member Kathy Gibson cofounded High Country Apps, a startup with a growing collection of apps that help users identify wildflowers. This is the first article in a series featuring IEEE members who have founded startups.
- **TEN QUESTIONS FOR SHOOP** To help members get to know IEEE President Barry Shoop, *The Institute* asked him about his college days, his vision for IEEE's future, and his favorite technology prediction that didn't come true.

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FROM LEFT: UNIVERSITY OF VIENNA; RANDI KLETT; DAN PAGE; SPECTRUM.IEEE.ORG

BACK STORY_

Giving Wackiness Its Due

DURING THE 20TH CENTURY were born some miraculous technologies: heterodyne radio, the laser, the transistor, the integrated circuit. And there were also quite a few more that were...well, not so miraculous and stillborn. A giant robot designed to service atomic bomber aircraft that were never built. Hugo Gernsback's "TV Glasses." A *portable* sauna bath.

These and countless other such instances occurred long ago and were promptly and understandably forgotten. But not quite completely forgotten, thanks to another 20th-century invention: the press release. And starting this month, we will pay homage to these curios in a new back-page column, Past Forward, by Contributing Editor Evan Ackerman [above, with NASA's Valkyrie robot].

Conceived by Senior Editor Jean Kumagai and Photography Director Randi Klett, the column will be a guided tour of some of the most bizarre moments from a heady era in technology. Basically, Klett will supply the photos, and Ackerman will supply the snark.

Alert readers will recognize Ackerman as part of the high-octane engine that powers our Automaton blog. He has loved sci-fi since childhood, and notes that many of the images we'll use in Past Forward echo the sci-fi of their era, the 1950s and '60s. "People were just as fascinated by the amazing weirdness of emerging technology back then as we are now," he says. "And it's fun to think about, 40 or 50 years from now, what people will think of the pictures we're publishing in *IEEE Spectrum*." ■

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SENIOR EDITORS
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Jean Kumagai, j.kumagai@ieee.org
Samuel K. Moore (News), s.k.moore@ieee.org
Tekla S. Perry, t.perry@ieee.org
Philip E. Ross, p.ross@ieee.org
David Schneider, d.a.schneider@ieee.org

DEPUTY ART DIRECTOR Brandon Palacio, b.palacio@ieee.org
PHOTOGRAPHY DIRECTOR Randi Klett, randi.klett@ieee.org
ASSOCIATE ART DIRECTOR Erik Vrielink, e.vrielink@ieee.org

SENIOR ASSOCIATE EDITORS
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Eliza Strickland, e.strickland@ieee.org
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VIDEO PRODUCER Kristen Clark, kristen.clark@ieee.org
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EDITORIAL RESEARCHER Alan Gardner, a.gardner@ieee.org

ADMINISTRATIVE ASSISTANT
Ramona L. Foster, r.foster@ieee.org
INTERN Qinrui Hua (Photo)

CONTRIBUTING EDITORS
Evan Ackerman, Mark Anderson, John Blau, Robert N. Charette, Peter Fairley, Tam Harbert, Mark Harris, David Kushner, Robert W. Lucky, Paul McFedries, Prachi Patel, Richard Stevenson, Lawrence Ulrich, Paul Wallich

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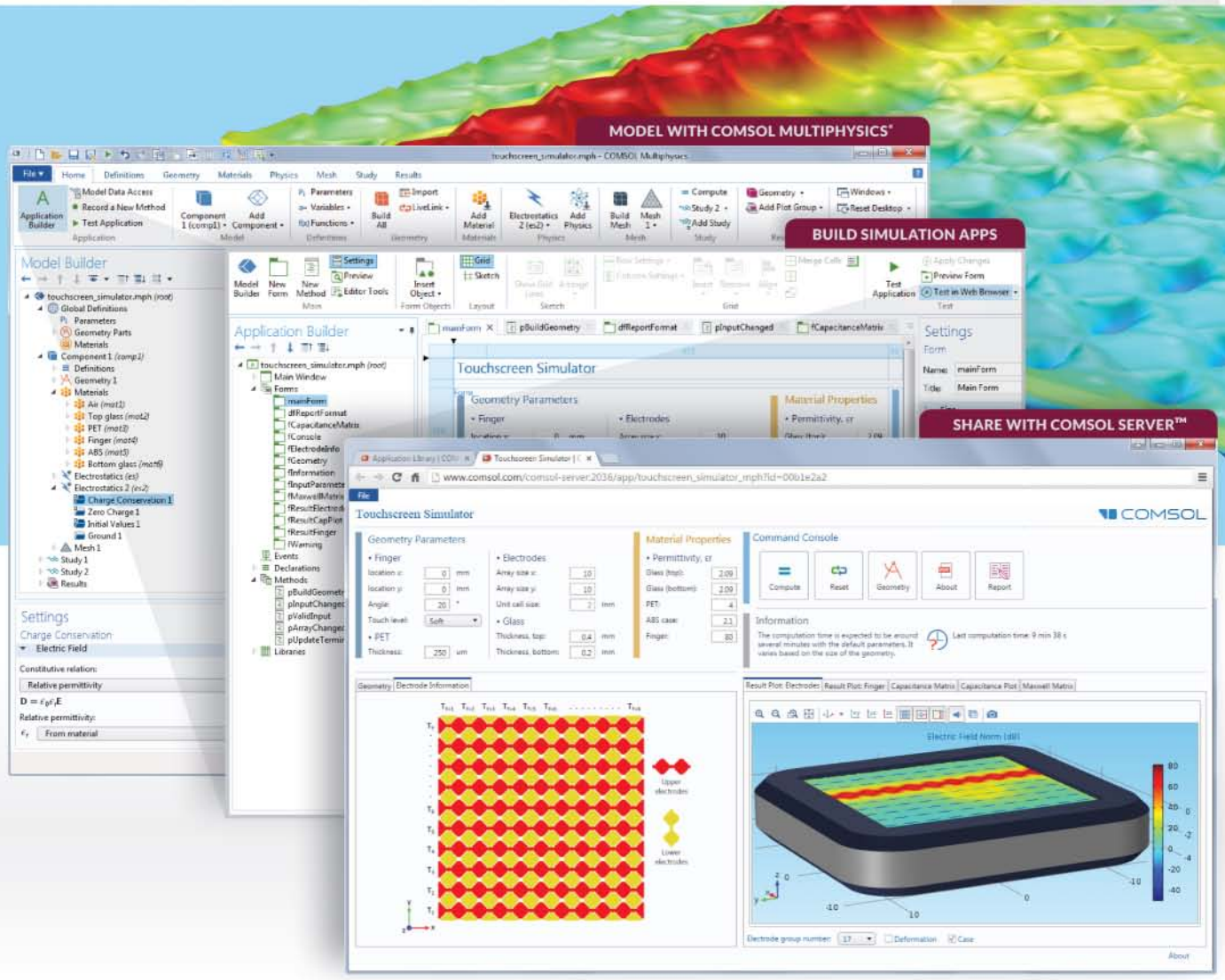

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CONTRIBUTORS_

Michael Dumiak

Dumiak is a reporter based in Berlin, from where he's covered science, technology, and culture since 2004 for such magazines as *Scientific American*, *Popular Science*, and *Wired UK*. In this issue Dumiak describes Norway's switch from analog FM to digital broadcasts ["Northern Lights Out for Analog Radio," p. 44]. "It was neat to read early forecasts for digital radio, some of them 10 years old, and go back to their sources," he says: "Hello? It's the future, calling about your report...."

Peter Fairley

A contributing editor at *IEEE Spectrum*, Fairley often writes about energy and the environment. In last January's Top Tech issue, he described the world's largest photovoltaic power plant, which helped him earn top honors from the Society of Environmental Journalists. The setting for his article in this issue ["Robot Miners of the Briny Deep," p. 40] never sees any sunlight. "I got no tan from on-site reporting this year," says Fairley. "But that didn't make the assignment any less intriguing."

Jeremy Hsu

When Hsu first reported on high-performance computing, his impression was that "the international race to build more powerful machines would keep going." Since then, he says, "I've become more aware of how supercomputing is fast approaching the limits of today's computing technologies—especially its rising power consumption." In this issue [p. 12], he explores the three paths supercomputing could take to reach its next big milestone: exascale computing, for performing a billion billion calculations per second.

Susan Karlin

Based in Los Angeles, longtime *IEEE Spectrum* contributor Karlin has attended Burning Man for the past six years, often covering its science and technology sectors and their impact on the outside world. In this issue she profiles Burning Man's technology director [p. 20]. "Heather Gallagher illustrates not only the event's organizational level but also its progressiveness," Karlin says. "How many other places would enable a woman with blue dreads to thrive as an engineering leader?"

Nathaniel Welch

Welch, a New York City–based photographer, is known for dynamic portraits of athletes. He has fond memories of photographing Venus Williams as she smashed tennis balls into a studio wall. Welch brought the same vigorous sensibility to the photo shoot of a paraplegic man who will cycle in the world's first cyborg Olympics [p. 26]. But this time Welch wasn't trying to capture the power of the unaided human body—instead he showed the strength that arises "where technology meets humanity," he says.

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CORPORATE ACTIVITIES Elena Gerstmann
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TECHNICAL ACTIVITIES Mary Ward-Callan
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New Year, New Projects. Same Old Ethics?

Volkswagen's emissions scandal spotlights the engineer's dilemma

LATE LAST YEAR, I SPENT AN AFTERNOON taking IEEE's online training in compliance and ethics, a program designed to make sure its staff and volunteers understand the laws, regulations, and policies that govern the organization in its operations around the world. The classes cover rules against bribery, how to recognize conflicts of interest, what constitutes data privacy and security, and employee law in the workplace. I was impressed by the number and variety of issues surveyed.

Since the 1970s or so, codes of conduct, ethics, and compliance have flourished in corporations and organizations around the globe.

Volkswagen, maker of "the people's car"—and of the people's latest diesel-emissions scandal—has a robust code of conduct. It also has a dedicated compliance ombudsman system that allows employees to report wrongdoing anonymously. So what went wrong?

The automotive industry is no stranger to business skullduggery, but what was startling was VW's big bet—a gamble that the deliberate manipulation of emissions-testing results, by algorithm and by hand, would never be discovered. And it almost wasn't.

We can all make reasonable guesses as to how VW's best intentions met defeat while we wait for the facts of the matter to be revealed. Growth-driven insanity? Groupthink overriding reason? Maybe it was a boardroom-level decision to do a little cheating now to buy time to deal with the problem of balancing emissions and good performance later. Some of *Spectrum*'s online commenters think it's much ado about nothing; others see it as a dangerous criminal act. Almost all believe that the engineers involved will be the fall guys for managerial malfeasance. It's starting to look as though they already have.

I spoke with Stephen Unger, professor emeritus of computer science and electrical engineering at Columbia University, one of the founders of IEEE's Society on Social Implications of Technology and author of *Controlling Technology: Ethics and the Responsible Engineer* (Wiley, 1994), about the VW situation.

He thinks it's pretty obvious why any engineers who may have been involved have not come forward to date. For one thing, anyone who does stand up will most likely be swept aside. For another, while engineers are a professional class, they are, by and large, employees, and these days, often temporary employees. Confronted with questionable orders or restrictions, they find themselves in the untenable situation of having to do something unethical—which includes going along with it and remaining silent—or face career damage.

And yet, if you look at any Gallup poll from the last decade in which people are asked to rank the professions they think are most honest and ethical, engineers are always somewhere in the top 10. They are responsible for the marvelous new technology we show you in this issue.

And that, according to Unger, is the dilemma of engineers: how to live up to professional expectations when they're creating and applying technology but don't have an opportunity to weigh in on how, in the end, that technology is used.

All the compliance training and whistle-blowing in the world couldn't save VW from itself.

Perhaps our best bet is to assume that any system that involves humans and technology and power and money will inevitably experience an ethical meltdown. What steps can we take to recover from the fallout quickly and apply any lessons learned to new techno-ethical predicaments just now materializing on the horizon? —SUSAN HASSLER

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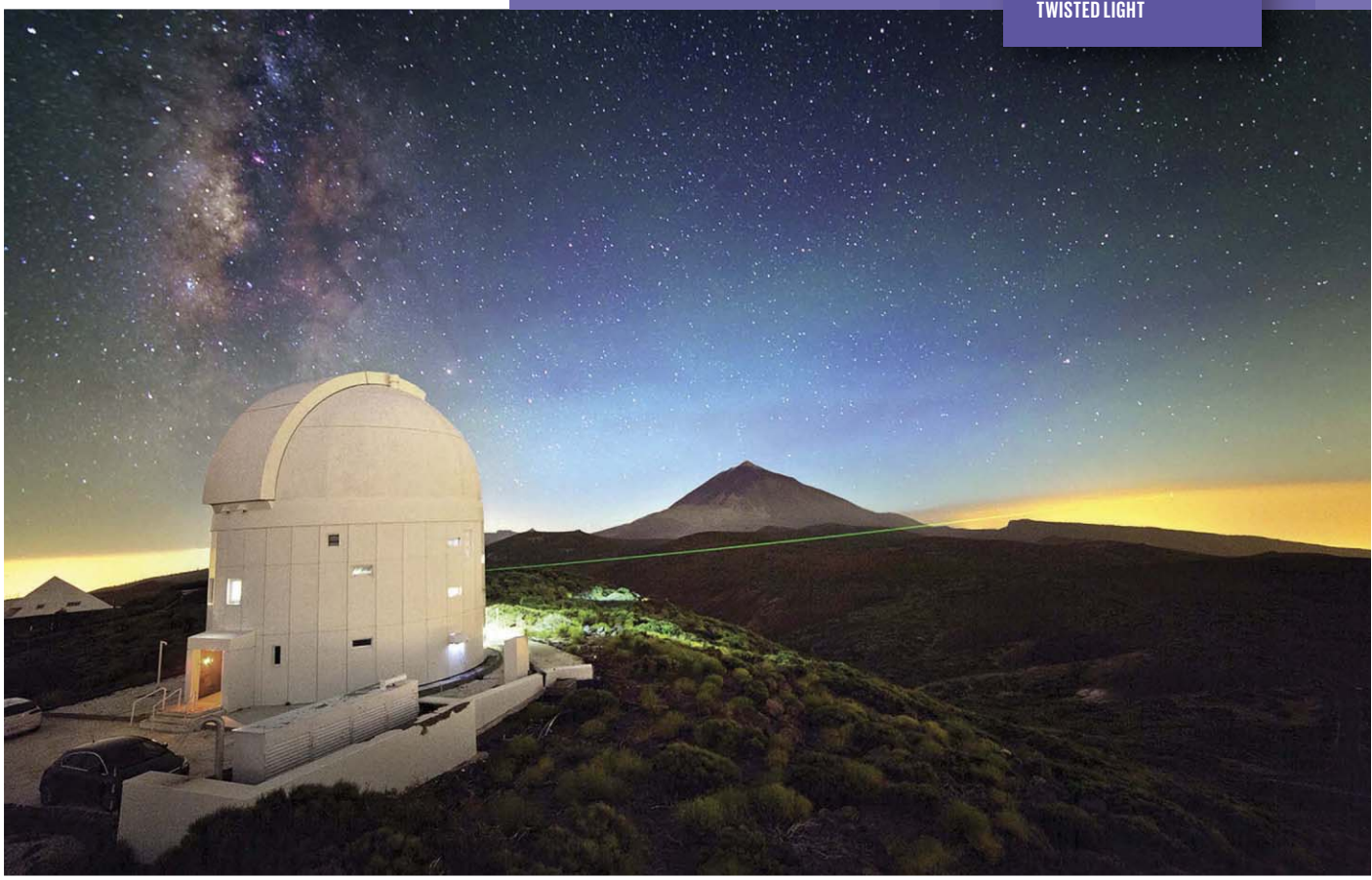

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TWO STEPS CLOSER TO A QUANTUM INTERNET

Einstein's "spooky action at a distance" can reach as far as low Earth orbit, and twisted light could boost quantum communication bandwidth

LASER LEVEL: The green beam maintains alignment between sender and receiver stations located 143 kilometers apart.

In theory, the counter-intuitive workings of quantum mechanics can guarantee that digital communications are utterly immune to prying eyes. That theory has advanced quickly, but the practice is now catching up, thanks to two developments by one of the field's pioneers.

University of Vienna physicist Anton Zeilinger and his team realized the first teleportation of photons in 1997. Not to be confused with the stock-in-trade of *Star Trek*'s Montgomery Scott, teleportation is the instantaneous transfer of the properties of one particle to another distant one; it's key to perhaps the most unassailable version of quantum communications. In November, Zeilinger and his team reported that they'd taken the process two important steps further.

First, they teleported not just a photon's usual properties but also its strangest one: entanglement. What's more, they did it over a record distance of 143 kilometers, linking the »

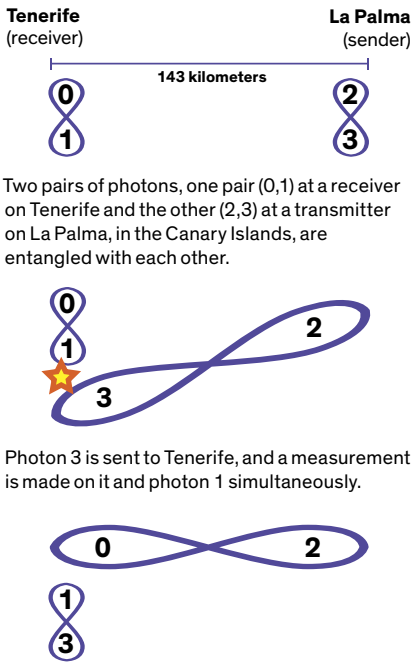
Canary Islands of La Palma and Tenerife. That distance is particularly significant, because it's nearly as far as the boundary of low Earth orbit.

Second, they pulled off a similar feat—although over a much shorter distance—using twisted light, the kind featuring photons having a property called orbital angular momentum. Photonics experts hope orbital angular momentum could hugely increase the bandwidth of optical telecommunications networks.

Entanglement is a quantum phenomenon. When a pair of particles, such as photons, are created in a single physical process or interact with each other in a particular way, they become entangled—that is, they start behaving like a single particle, even when they become separated by any distance.

Teleportation of entanglement, also known as entanglement swapping, makes use of another curious phenomenon: It's also possible to entangle two photons by performing a joint measurement on them, known as a Bell-state measurement. Once these photons are linked, switching the polarization of one of them—say, from up to down—causes an instantaneous switch of the other photon's polarization, from down to up.

ENTANGLEMENT SWAPPING



Two pairs of photons, one pair (0,1) at a receiver on Tenerife and the other (2,3) at a transmitter on La Palma, in the Canary Islands, are entangled with each other.

Photon 3 is sent to Tenerife, and a measurement is made on it and photon 1 simultaneously.

Photon 1 and 3 are now entangled, and so are photons 0 and 2—despite the fact that they never came near each other.

Here's how the entanglement swap works: Assume you have two pairs of entangled photons, 0 and 1 in the receiving station and 2 and 3 in the transmitting station. Both entangled pairs are completely unaware of each other; in other words, no physical link exists between them. Now, assume you send photon 3 from the transmitter to the receiver and perform a Bell-state measurement simultaneously on photon 3 and on photon 1. As a result, 3 and 1 become entangled. But surprisingly, photon 2, which stayed home, is now entangled with photon 0, at the receiver. The entanglement between the two pairs has been swapped, and a quantum communication channel has been established between photons 0 and 2, although they've never been formally introduced [see illustration, "Entanglement Swapping"].

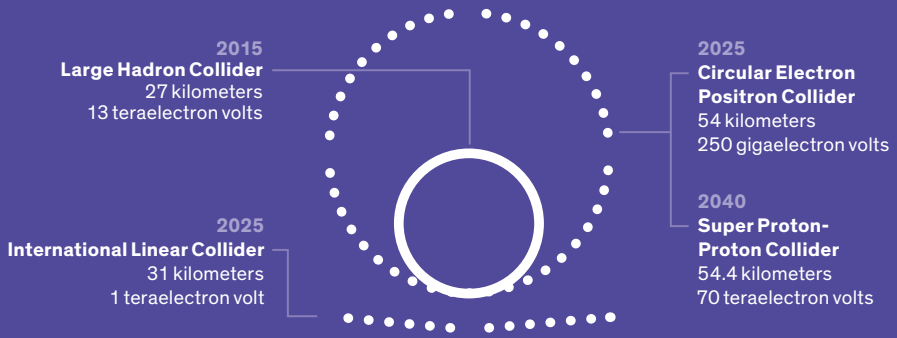
Entanglement swapping will be an important component of future secure quantum links with satellites, says Thomas Scheidl, a member of Zeilinger's research group.

The team is working with a group at the University of Science and Technology of China on a satellite project led by Zeilinger's former Ph.D. student Jian Wei Pan. Next year, when the Chinese Academy of Sciences launches its Quantum Science Satellite—which will have an onboard source of entangled photons—the satellite and ground stations in Europe and China will form the first space-Earth quantum network. They will implement a quantum-key relay protocol, securely linking the ground stations in Europe and China, says Scheidl.

The Quantum Science Satellite will be launched into a low Earth orbit and will communicate with one ground station at a time. "The satellite flies over a ground station in Europe and establishes a quantum link to the ground station, and you generate a key between the satellite and the ground station in Europe. Then, some hours later, the satellite will pass a ground station in China and establish a second quantum link and secure key with a ground station in China," Scheidl explains.

THE COMING COLLIDERS

With an upgraded Large Hadron Collider (LHC) back to smashing protons, it's time to think about what comes next. The International Linear Collider (ILC), which had been the designated successor, would impel particles with only a fraction of the energies of the LHC, but it would still yield a better understanding of the Higgs boson. Now Chinese scientists have revealed that they're planning something even bigger. China's proposed Circular Electron Positron Collider would initially hit 250 gigaelectron volts, or about one-fourth the ILC's energy. But at the end of this first phase's life span, the buried ring of superconductors—whose circumference is about twice that of the rings in the LHC—will be upgraded to become the Super Proton-Proton Collider, a machine capable of 70 teraelectron volts, or five times as much as what the LHC can produce.



"The satellite then has both keys available, and you can combine both keys into one key," he adds. "Then you send, via a classical channel, the key combination to both of the ground stations. This you can do publicly because no one can learn anything from this combined key. Because one ground station has an individual key, it can undo this combined key and learn about the key of the other ground station."

The future quantum Internet will need a network of satellites and ground stations, similar to that of the Global Positioning System, in order to exchange quantum keys instantaneously.

Kilometer distances for transmitting twisted light—light having an orbital angular momentum, or a wave front that resembles fusilli pasta—were proved possible a year ago by the Vienna team. "Last year was a necessary step, and it was successful," says Mario Krenn, a member of Zeilinger's research group. They knew that entangling twisted photons was the next step that could increase the bandwidth of quantum-key generation. And that's just what Krenn and his colleagues have done, entangling twisted photons and sending them 3 kilometers from each other: "We were able to show that on the single photon level, each photon can keep information in the form of orbital angular momentum over a large distance and can be entangled even after 3 kilometers."

The control of twisted quantum states is much more complicated than the control of polarization states, but the possibility of being able to entangle photons on multiple levels is worth the effort, says Krenn. Photons can exist only in two polarization states or levels, up and down. But the number of orbital angular momentum states is, in theory, unlimited, explains Krenn. "In the lab, we have shown that we can create a 100-dimensional entanglement—up to a hundred different levels of the photons can be entangled." And that will mean a truly high-bandwidth, uncrackable global network. —ALEXANDER HELLEMANS

EVAN ACKERMAN

WIRELESS POWER TAKES CHARGE

Is wire-free charging of consumer devices ready for mainstream adoption?

In 1891, Nikola Tesla performed an amazing demonstration: He illuminated a gas discharge tube (essentially a fluorescent bulb) with an electric field, showing that it was possible to transmit electric power without wires. Since then, advances in electronics and computing have given us portable versions of his contemporaries' inventions—Bell's telephone and Edison's phonograph. But when it comes to powering up those devices, we're still tethered in place.

The best we've managed to engineer so far is inductive charging: Place your cellphone on top of a resonant inductive charging pad and the pad's oscillating magnetic field generates a current in the phone's receiving antenna. The wire may be gone, but the device is still closely bound to the pad until it's charged, which isn't quite what Tesla had in mind.

Real progress on wireless power might come as soon as this year. Several companies are promising to deliver the kind of charging that we really want: technology that can charge devices while they're in our hands, in our pockets, or wherever we happen to put them down. "Promising" is the key word here. Though these systems seem like magic, it's important to temper any excitement with a healthy dose of the reality imposed by the laws of physics.

Silicon Valley startup Energous Corp. is developing a technology it calls WattUp. At CES 2015 in Las Vegas, *IEEE Spectrum* saw a private demo of WattUp's transmitters delivering energy to devices via microwave beams, and we were impressed. Hundreds of small antennas embedded in speakers, televisions, and dedicated router-size boxes directed power to toys, lights, and cellphones over distances of several meters.

WattUp's sophisticated localization and beam-forming technology allows multiple radio frequency antennas to emit low-power, 5.8-gigahertz beams along different paths

LOOK, MA! NO WIRES: WattUp's microwave beam antennas can wirelessly charge a cellphone from across a room.

that converge in a "pocket" around the targeted device. Together, they generate enough RF power for a metamaterial receiving antenna to harvest. The device—say, a cellphone—is tracked in real time, and the beam paths are continuously updated with its location. The microwaves can bounce off surfaces, so as the device moves, the microwaves can reach the receiving antenna even if it's not in a WattUp transmitter's direct line of sight.

Energous recently commissioned a performance evaluation from Underwriters Laboratories. UL verified that, under ideal conditions, a WattUp transmitter is capable of delivering microwaves to up to four devices simultaneously. The amount of power the beams deliver is dependent on distance: 4 watts within 1.5 meters, 2 W within 3 meters, and 1 W within 4.6 meters. Energous wouldn't comment on the end-to-end efficiency of the system during this test, except to say that its eventual goal is 25 percent efficiency. While it has yet to receive the approval of the U.S. Federal Communications Commission, Energous says it plans to make a splash this month at CES 2016 with an announcement of substantial efficiency improvements and integration into near-market consumer devices.

Energous has a competitor in Ossia, based in Redmond, Wash., which is also developing an RF power delivery system. But engineers at the University of Washington have taken a completely different approach, showing that a reliable source of wireless power is hiding in plain sight. Vamsi Talla, a UW electrical engineering doctoral student, is the lead author of a paper describing Power Over Wi-Fi (PoWiFi), which can distribute tiny but useful amounts of power using an ordinary Wi-Fi router.

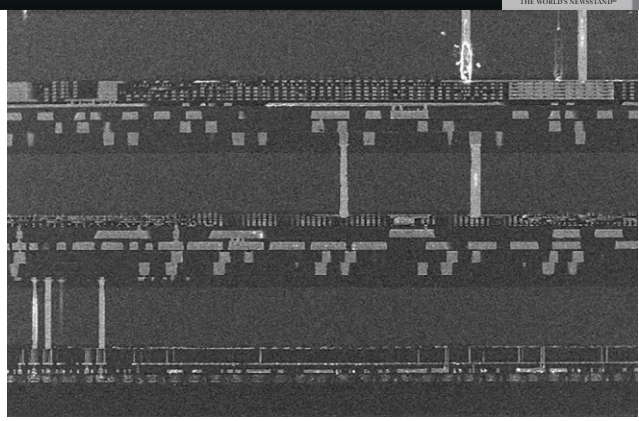
Your existing Wi-Fi router, transmitting at full strength, emits enough RF power, at least in theory, to operate or gradually charge very small devices at ranges approaching 10 meters. In practice, this isn't realistic because your router emits power only when it's sending data packets. Instead, PoWiFi keeps a stream of "superfluous broadcast traffic" flowing so that the router's power output is kept at the maximum; this flow of nonessential packets is intelligently managed to avoid interference with the user's actual Web surfing.

As with WattUp's microwave beams, the amount of power transferred from PoWiFi's custom routers to its RF harvesting antennas depends strongly on distance. According to Talla, temperature sensors placed more than 8 meters from a router collected enough charge to return data every few seconds. A modified consumer fitness device left within a few centimeters of a router went from zero to a 41 percent state of charge in 2.5 hours. Six PoWiFi routers, tested in the homes of volunteers, had no discernible impact on the quality of the users' Internet access.

RF isn't the only charging modality being promised for 2016. Israeli startup Wi-Charge uses beams of infrared light, and Santa Monica, Calif.-based uBeam relies on ultrasound. uBeam's recent technical disclosures, and the fact that we've yet to see an operational acoustical-to-electrical-energy prototype, have left experts with one big question: How can ultrasound—which needs an unimpeded path and attenuates rapidly in the air—lend itself to power transmission in a world filled with stuff like, say, furniture? [See "Experts Still Think uBeam's Through-the-Air Charging Tech Is Unlikely," *IEEE Spectrum*, November 2015.]

Wireless tech will probably never match the efficiency and effectiveness of a plug in a wall socket. But even if real-world end-to-end efficiency ends up in the single digits—well below Energous's hoped-for 25 percent—our guess is that it won't stop many people from wanting to give wireless charging a try. —EVAN ACKERMAN

How can ultrasound—which needs an unimpeded path and attenuates rapidly in the air—deliver power in a world filled with stuff like, say, furniture?



TEZZARON SEMICONDUCTOR

THREE PATHS TO EXASCALE SUPERCOMPUTING

Specialized architecture, millivolt switches, or 3-D memory can get you there—for a price

For most of the decade, experts in high-performance computing have had their sights set on exascale computers—supercomputers capable of performing 1 million trillion floating-point operations per second, or 1 exaflops. And we're now at the point where one could be built, experts say, but at ridiculous cost.

"We could build an exascale computer today, but we might need a nuclear reactor to power it," says Erik DeBenedictis, a computer engineer at the Advanced Device Technologies department at Sandia National Laboratories, in Albuquerque. "It's not impossible; it's just a question of cost."

Although nuclear reactors are its forte, the U.S. Department of Energy aims to use a more modest power source when it brings its first exascale supercomputer on line sometime in the 2020s. The goal is to have the machine consume no more than 20 megawatts.

Since 2012, DeBenedictis has been working with the IEEE Rebooting Computing initiative and the International Technology Roadmap for Semiconductors on a practical way to get to exascale. He sees three technologies that will lead the way forward: millivolt switches, 3-D stacked memory chips, and specialized processor architectures. Each involves some trade-offs, particularly in the realm of software specialization and because it will be difficult to predict when the technologies could be deployed. —JEREMY HSU

STACKS UP NICELY: A 3-D memory stack from Tezzaron Semiconductor boosts speed and reduces power draw.

THE MILLIVOLT SWITCH

In accordance with Moore's Law, engineers had hoped that operating voltages for silicon transistors would continue to fall along with transistor sizes. Instead, the once steady improvement in operating voltages has remained stuck at close to 1 volt for the past decade.

"We could theoretically lower the operating voltage from where it is now—about 800 millivolts—to a few millivolts," says Eli Yablonovitch, a computer engineer and director of the National Science Foundation's Center for Energy Efficient Electronics Science at the University of California, Berkeley. Such a "millivolt switch" would be a radical solution to supercomputing's energy efficiency problem. But it remains an elusive goal.

Nobody knows how a millivolt switch might become a reality, and worse—from the standpoint of building exascale computers in the near future—nobody knows when. But Yablonovitch's center has chosen to focus on four possibilities. First, there's a device called a tunnel field-effect transistor, or tunnel FET: Switching it on makes the electronic barrier between the two sides of the transistor so thin that electrons are more likely to "tunnel" through it [see "The Tunneling Transistor," *IEEE Spectrum*, October 2013]. A second possibility is tiny nanoelectromechanical switches that would conserve power because little current can leak across an open switch [see "MEMS Switches for Low-Power Logic," *Spectrum*, April 2012]. Third, nanophotonics could enable faster, lower-power communication between switches by replacing physical wires with light signals. And fourth, logic circuits based on nanomagnetics could pave the way for lower energy, nonvolatile circuits [see "Better Computing With Magnets," *Spectrum*, September 2015].

Yablonovitch coined *millivolt switch* to illustrate the far-reaching potential of "an energy version of Moore's Law," he says. Sandia's DeBenedictis thinks it won't have quite as huge an impact as Moore's Law did, but even so, he estimates that a millivolt switch could improve efficiency by 10 to 100 times.

MEMORY IN 3-D

The U.S. Department of Energy's vision of a 20-MW exascale supercomputer would reserve 30 percent of the power budget for memory. That power budget goal will require memory-stacking architecture that improves on 3-D stacked DRAM, which puts towers of memory chips closer to a computer chip's processor units.

Such an arrangement means shorter interconnects between the units—and less power lost to capacitance and resistance when transferring bits of data. Even better, they also mean quicker communication [see "Memory in the Third Dimension," *Spectrum*, January 2014].

Stacked memory has already caught on in the broader computing industry. Before 2011, tech giants merely tinkered with it as "science fair projects," says Robert Patti, chief technology officer and vice president of design engineering at Tezzaron Semiconductor, which has worked on U.S. government supercomputing projects. But since that time, big chipmakers have all developed and commercialized different versions of 3-D stacked memory.

For its part, Tezzaron has pioneered a method of designing and manufacturing 3-D memory stacks that boosts memory performance, enables a higher density of interconnects between each memory chip layer, and reduces manufacturing costs.

"In a lot of ways, 3-D integration allows you to have your cake and eat it too," Patti says. "You get speed improvement and power reduction at the same time."

Exascale supercomputing may need to rely less on volatile DRAM—computer memory that holds data only while powered—and move toward more nonvolatile yet fast storage such as resistive RAM, Patti says. A new architecture based on 3-D memory stacking would also require some software retuning as memory access latencies change. But once that's done, using more memory to upgrade a 1-exaflops supercomputer to 2, 3, or 4 exaflops wouldn't result in a system that consumes much more power, says DeBenedictis.

SPECIALIZED CHIP ARCHITECTURE

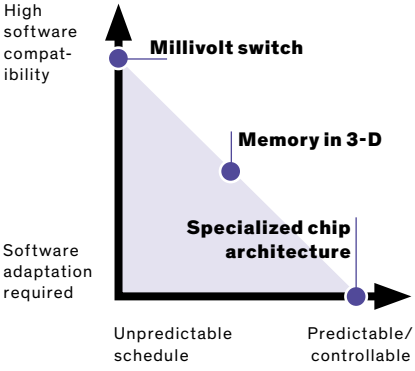
Adding specialized cores to computer processors designed to run only a few specific applications might help save on supercomputing's future power budget. Each part of the chip would run at full power only when its particular function is needed and would be powered down when it's not.

But such specialized architectures would also require programmers to tailor their software to make use of the added efficiency, and that would constrain what a particular supercomputer could perform efficiently.

"If you want something else, you will have to replace the chip with one of a new design," says DeBenedictis. He believes that such specialized architectures will likely become a part of exascale supercomputing. As the cost of making chips continues to go down, building a general-purpose supercomputer from specialized chips with dedicated functions might become reasonable.

EXASCALE TRADE-OFFS

The road to an exaflops supercomputer won't be smooth. The millivolt switch, for example, would dramatically reduce power draw. But how to make one, and when it would be ready, is anybody's guess.



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HAS TAIWAN GIVEN UP ON SUPERCOMPUTING?

Despite the country's stature as a chip powerhouse, it lacks world-class computing

A quick glance at the new ranking of top supercomputers reveals a surprising showing by one of the world's technological powerhouses: Taiwan does not possess a single machine powerful enough to make the Top500.org list. While there are many nations that don't make the list, Taiwan is peculiar in that it has such an outsized grip on the computer chip industry. What's more, its political rival, China, not only has the world's top machine, it now has more ranking supercomputers than any nation except the United States.

It has been a long decline. Taiwan's most powerful supercomputer, the Advanced Large-scale Parallel Supercluster, also known as ALPS or Windrider, ranked 42nd in June 2011, shortly after its launch.

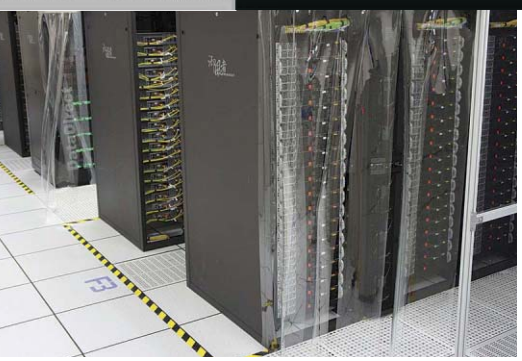
But the process of upgrading Taiwan's supercomputing infrastructure has been slowed by ineffective government budget allocation. Since 2013, the National Center for High-performance Computing (NCHC), located in Hsinchu City, which operates Windrider, has failed twice to get enough of a budget boost to strengthen its supercomputing ability. While other countries poured money into the installation of powerful supercomputers as a way to show national power, Windrider fell to 303rd and then 445th in June 2014 and June 2015.

"If our three-year budget proposal is approved early [in 2016], Taiwan would gain a much better position on the Top 500 in 2018, when a 2-petaflops system is launched," says Jyun-Hwei Tsai, deputy director general of NCHC. If such a system were launched today, it would rank 36th.

Officials at the Ministry of Science and Technology say they have prioritized supercomputing in their annual budget proposal–as they did in 2013 and in 2014. However, it's really up to "the Cabinet," the executive branch of the Chinese government.

Cabinet spokesman Sun Lih-chyun says the government fully understands the importance of supercomputing and points out that Taiwan has promoted cloud computing and big-data projects. "It remains uncertain when sufficient budget would be made available for new systems. We're still reviewing the budget proposal. The decision has not yet been made," Sun says.

"The Cabinet will make a final decision early [this] year," adds Tzong-Chyuan Chen, director general of the Department of Foresight and Innovation Policies under the ministry. "In economic recession years, it's difficult to gain budget for important science



WINDRIDER AGROUND: Taiwan's most powerful computer has fallen off the Top 500 list.

NCHC

and technology projects with long-term impacts, which are not yet felt."

It wasn't always like this. In June 2002, an IBM system at the NCHC center ranked 60th. In June 2007, the center's newest system, called Iris, ranked 35th.

Iris's place on the list wasn't long-lived. It was displaced by November 2009 due to a boom in supercomputer installations in many other countries, such as China. The huge increase in China's supercomputing power in recent years can be attributed in part to some government-backed companies, such as Sugon Information Industry Co. and Inspur Group Co., which together manufactured 64 of the ranked systems.

According to NCHC's Tsai, the big strides taken by other countries is a sore point in Taiwan. "We don't compare ourselves with big countries, such as China, Japan, and the United States. What frustrates us more is that, in South Korea, the momentum of national supercomputing is now stronger than ours," he says. Currently, South Korea's two fastest systems rank 29th and 30th.

It's not as if there isn't much demand for supercomputing in Taiwan. Currently, Taiwan's Windrider utilization exceeds 80 percent. "It's like a crowded superhighway. And we've heard complaints from some users," Tsai says.

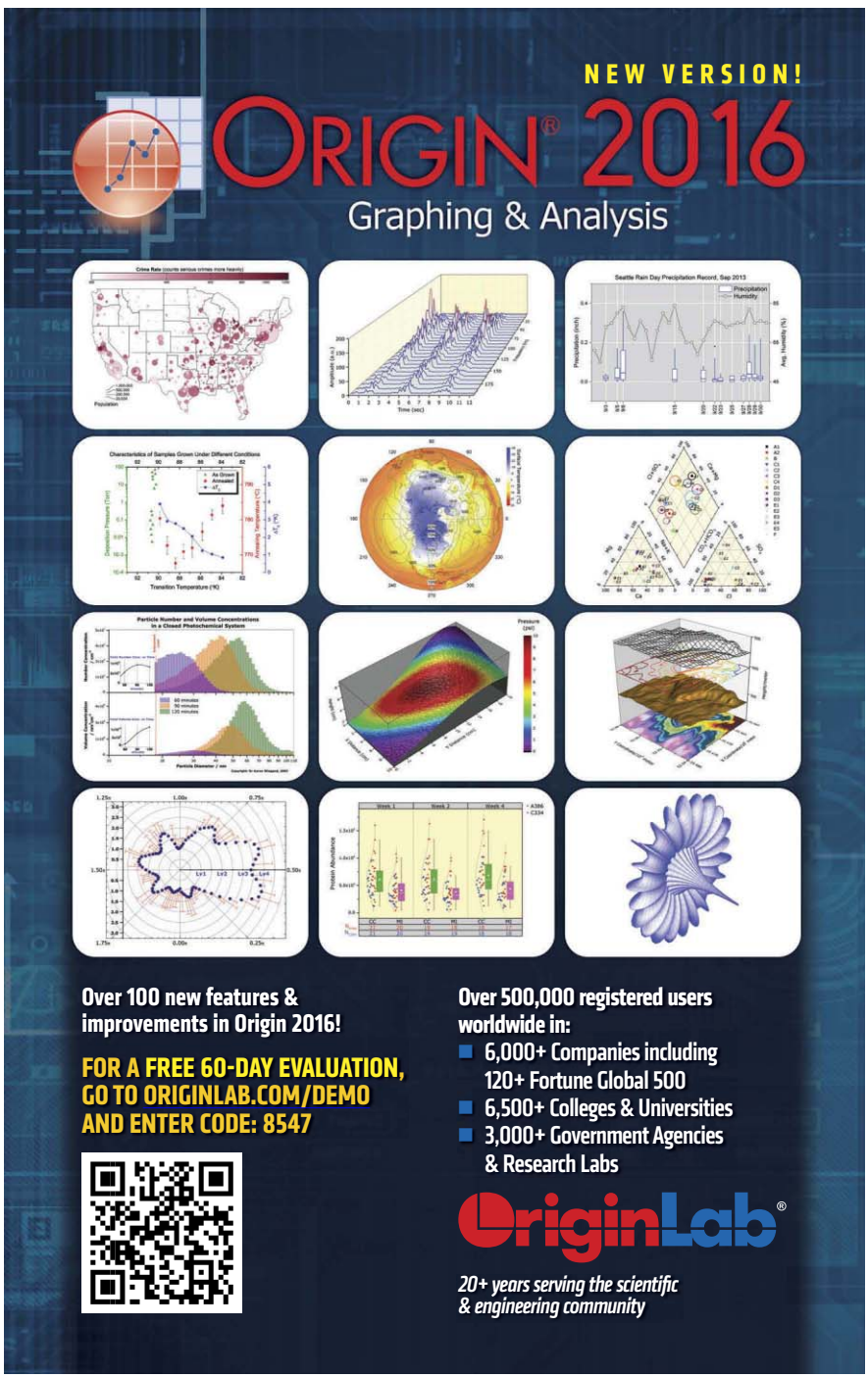
According to Tsai, Windrider is most significantly used in basic physics, chemistry, and biomedical imaging. But certain key fields get prioritized access. Those include environmental studies, climate change, and natural disasters.

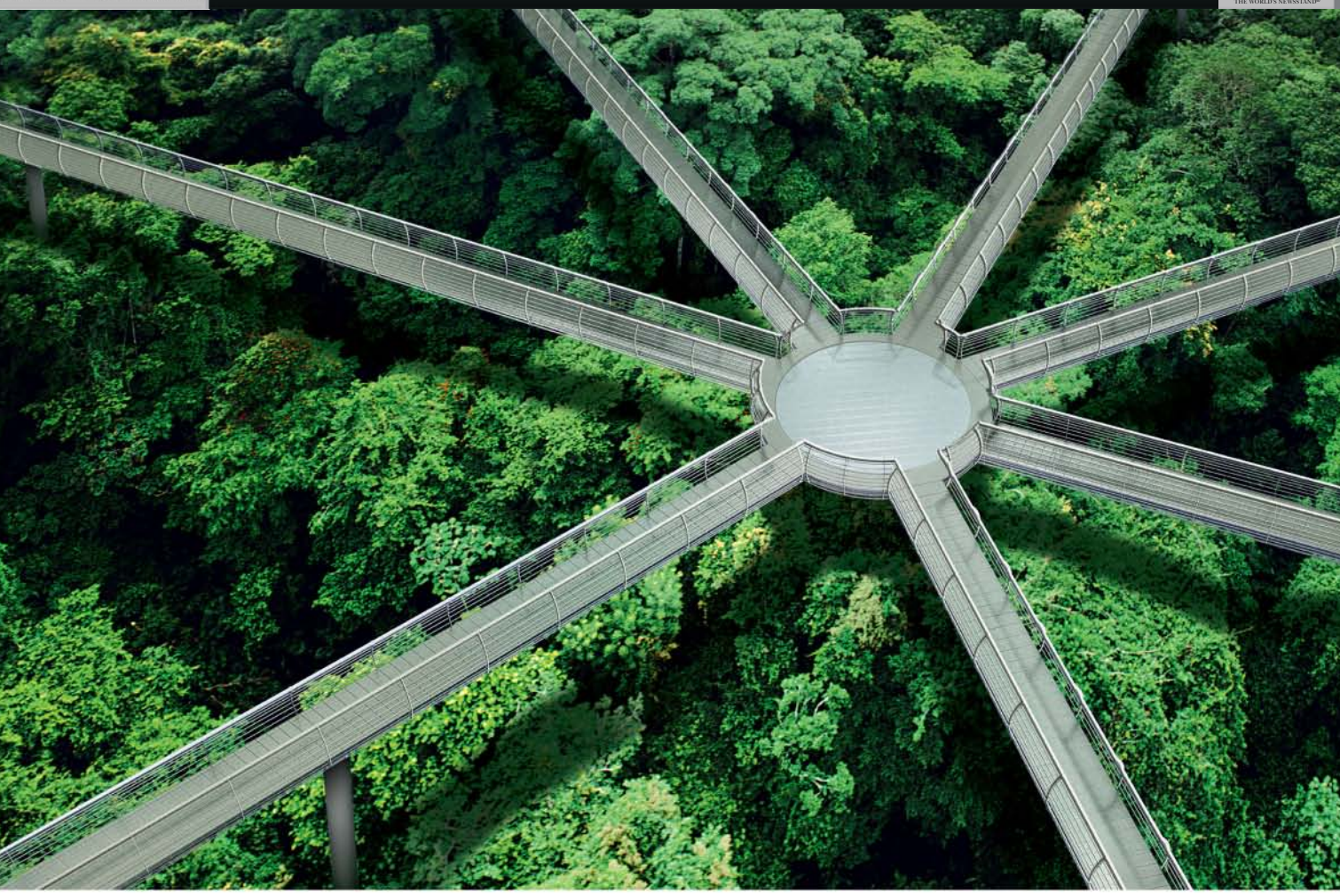
"Taiwan is prone to natural disasters, such as typhoons, floods, and earthquakes. A powerful database, backed by powerful supercomputing systems, is essential for conducting better predictions of typhoons," Tsai says.

Due to the limitations of Taiwan's supercomputing capability, some scientists have taken to building their own computer clusters and speeding up existing resources with graphics processing unit-based accelerators.

Tzihong Chiueh, a theoretical astrophysicist at National Taiwan University, in Taipei, says he and his colleagues there have not relied on NCHC's system for years. Chiueh, whose team has since 2013 been taking advantage of a self-built system that can reach tens of teraflops, says, "The investment [in a petaflops-scale system] should indeed be prioritized. I hope it can work at least 10 times faster than the current system."

—YU-TZU CHIU





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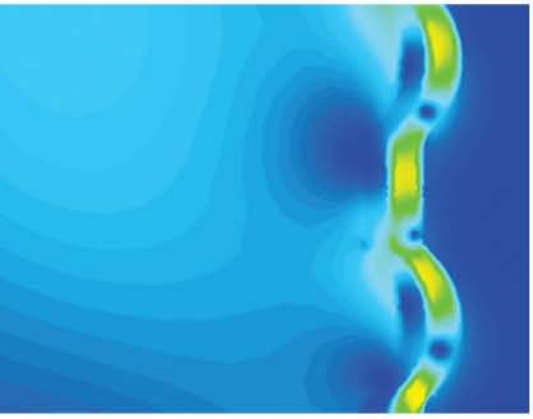

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RESOURCES

33

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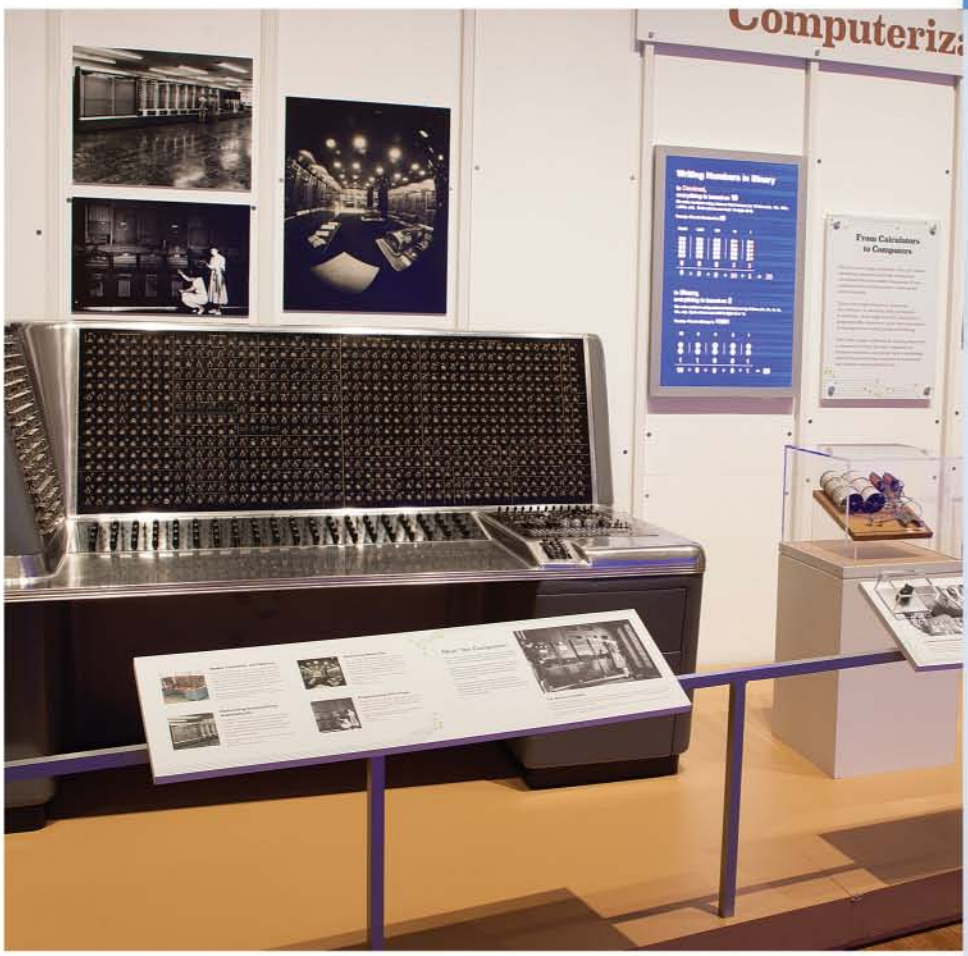

RESOURCES_REVIEW

NEW YORK'S DIGITAL PAST

BEFORE SILICON VALLEY, NYC WAS THE PLACE TO BE

DAS BLINKENLIGHT MACHINE: The switch- and bulb-festooned control desk of IBM's SSEC [left] is one of the highlights of the *Silicon City* exhibit.

RANDI KLETT

Why am I typing out these words in a New York City office building? Because *IEEE Spectrum* is located in the official global headquarters of the IEEE; when two earlier organizations merged to form the IEEE in 1963, it was written into the founding regulations that HQ would be in NYC. The city was the obvious choice at the time: For decades, New York had been at the heart of global electrical and electronic invention. Edison's first commercial power plant came to life in downtown Manhattan in 1882. During World War II, Alan Turing and Claude Shannon lunched together at the original Bell Telephone Laboratories location in Greenwich Village. And the surrounding area saw the first modern FM radio transmissions, the first transistor, and the first purely electronic color televisions. ● A new exhibition at the New York Historical Society celebrates this technological heritage. Called *Silicon City* and open until mid-April, the small but well-curated exhibition focuses on the city's role in the history of computing. ● The entrance to *Silicon City* includes mementos from the 1964 New York World's Fair, housed under a dome intended to evoke IBM's egg-shaped pavilion at the fair. In hindsight this event represented the peak of New York's command—and, by extension, that of the entire northeastern United States—over the global technological zeitgeist. And IBM-related items account for about half of the exhibition space. ● IBM provided significant support for *Silicon City*, so this sizable presence isn't a surprise. Perhaps, for example, the inclusion of a replica of Hollerith's 1890 census tabulating machine might be stretching a point, since the machines were developed and manufactured

in Washington, D.C. However, by and large, IBM's dominance is justified. In the years between World War II and the rise of mini- and microcomputers, IBM pretty much *was* computing in the United States. In the late 1940s and early 1950s, people walking by IBM's New York headquarters marveled at the giant Selective Sequence Electronic Calculator (SSEC), which had been installed in a room behind a large glass window. The SSEC is long gone, but visitors to *Silicon City* can marvel anew at its lovingly styled control desk, blanketed in switches and lights.

I was especially pleased to see a significant area devoted to early digital art. In 1966 a series of experimental performances were held at New York's 69th Regiment Armory (where the so-called 1913 Armory Show, which introduced modern art to the United States, also took place). These performances were the culmination of a collaboration between scientists and engineers from Bell Labs and leading artists of the day. *Silicon City* allows visitors to call up extracts of performances and related artwork, and is a powerful reminder that art and digital technology have gone hand in hand for decades. The original oscilloscope that William Higinbotham used to create the Ur-video game, *Tennis for Two*, is here as well.

The rise of California's Silicon Valley meant the end of NYC's high-tech golden age. In more recent years, however, the city has seen a tech revival, with many Web and mobile startups calling the city home (the low physical

ELECTRIC TOWN: New York City's large artistic community was fertile ground for early experiments in combining digital tech and art.

footprint of online businesses is some defense against a city that has seen spiraling rents as its industrial zones are relentlessly converted into luxury condos). *Silicon City* confines the dark years of the '70s and '80s, and the subsequent boom and bust of the great dot-com crash, to a small video exhibit, before moving on to a much sunnier and larger display focused on the present day. This features scenes from Manhattan and Brooklyn, boasting about the location of companies such as Etsy, Shapeways, and Tumblr, and showcasing some of their wares. But then, it wouldn't really be NYC without a little bit of braggadocio. **—STEPHEN CASS**

DIY HOME SECURITY
DETER INTRUDERS WITH AN EXTRALOUD ALARM

RANDI KLETT

THE LAST STRAW WAS A MIDDAY break-in right next door. For months, my wife and I had worried that our neighborhood in the Seattle suburbs was suffering from a nasty rash of home burglaries. We had toyed with getting a security system for our house but balked at the monthly fees and installation hassle of conventional systems. Then our neighbors alerted us that intruders had just busted into their home—only a few meters from ours—in broad daylight. ● I started researching DIY security systems the next day. Thanks to advances in mesh networking and Internet-of-Things standards like Zigbee and Z-Wave, the market has exploded with wireless security systems that are easy to install and expand, connected to smartphone apps, and much more affordable than their hardwired counterparts. Most of them include built-in batteries and 3G cellular radios, so they still work if the power or Internet router goes down. ● As I waded through the support forums of several promising-looking systems, however, I noticed a common complaint: Their sirens are pathetic. The "siren is not loud enough" thread on Scout Alarm's website, for example, had 156 posts from unhappy customers, along with (as yet unfulfilled) promises from the company to fix the issue by redesigning the case. It's surprising that none of the DIY systems make enough noise to scare off would-be thieves (or include terminals for connecting an external siren). Apparently their designers didn't have deterrence in mind. ● I decided to order a Scout system nevertheless. It offered the sensors I needed at an attractive price. I liked that it works with IFTTT (If This Then That), an IoT-unifying Web-based service that I wanted to use to flash a Lifx lightbulb on my nightstand when the alarm goes off. And I had an idea for amplifying the siren to be as loud as I wanted—an idea that should work with any security system, IFTTT-enabled or not (IFTTT can be sluggish responding to a trigger, not the kind of thing you want when trying to stop burglars in their tracks). All I had to do was to build a follower siren.

It's an idea borrowed from photography, where studios sometimes deploy extra stand-alone flashes that go off when an attached photodetector picks up the light of a flash directly attached to the camera. My gadget would similarly use a microphone to listen for the distinctive chirp of the Scout's alarm and then send a wireless signal on my local network to turn on and off a much louder siren in sync with the Scout.

Setting up the Scout was easy. It took less than an hour to configure the hub (US $129) by using the free iOS app and to link it to a couple of entry-door panels ($69 each), several door/window sensors ($29 each), and a few motion detectors ($49 each). I connected the system to IFTTT and configured an app called DO Button to let my wife and me arm or disarm the system with our phones.

For the listener part of the project, I bought an Arduino Uno ($20), an ESP8266 Wi-Fi shield for the Uno ($15), and a sound detector sensor board ($11) from SparkFun. Compared with more advanced microcontrollers, the Uno is smaller, cheaper, and can run on batteries. But its limited memory later proved problematic.

HOME-BREW HOUSE GUARD: A microphone connected to a Wi-Fi–enabled Arduino Uno listens for the Scout's alarms. A wireless switch turns on the siren.

I made things easy on myself on the siren side by buying Belkin's WeMo switch ($39), which connects to Wi-Fi and can toggle power to any appliance—in this case, a 9-volt power supply for a 110-decibel Honeywell Ademco 702 siren ($23). The WeMo also comes with a free smartphone app, which serves as a handy backup in case I need to sound or silence the siren manually. Belkin hasn't documented the TCP commands that control the switch, but helpful hackers have deduced them and posted Arduino sketches that can turn the device on or off via Ethernet.

All I needed to do was adapt that code to work with the Wi-Fi shield, and then use it as a function inside a larger program that monitored the frequency, intensity, and duration of the sounds picked up by the microphone board. Within a couple of hours, I had the chirp-detection algorithm built.

To calibrate it, I put the microphone right next to the Scout hub and triggered the alarm. The critics were right: Its cry for help is truly feeble—quieter than a phone ringing or the alarm on my clock radio. So quiet, in fact, that I wasn't convinced the sensor could distinguish it from background noise. Removing the hub cover revealed the problem: The piezo speaker is mounted so that sound is aimed directly into the thick plastic side of the device. I drilled a hole a little over a centimeter wide to expose the speaker to the air, and immediately the volume doubled—still not loud enough to deter an intruder, but sufficient to activate my chirp detector.

Then I hit the 2-kilobyte problem: My program demanded more RAM than the Uno offers, mainly due to the lengthy data packet it had to assemble and send to activate the WeMo. Savvy developers pointed me to a function that forces the compiler to store data in the much more expansive flash memory (intended for storing programs) rather than in the Uno's RAM. But that came at a heavy cost in speed: The Arduino took about 30 seconds to toggle the switch, when it worked at all.

Through trial and many errors, I finally worked out a way to keep the crucial data packets in RAM while stuffing most everything else into the flash. The final program loaded with memory to spare. Connecting all the pieces, I loaded up the Scout app and hit the "siren" button. Chirp, chirp, chirp… WHOOP, WHOOP, WHOOP. The big siren came on so loud and suddenly, I almost wet myself. I'm sure the neighbors heard it. And that's the point. **—W. WAYT GIBBS**

W. WAYT GIBBS (2)

BURNING MAN'S TECH MASTERMIND
HEATHER GALLAGHER MAKES THE INTERNET BLOOM IN THE DESERT

DOWNTIME: Heather Gallagher takes a rare break at the annual Burning Man festival.

Every year, around the beginning of September, tens of thousands of people go out into Nevada's Black Rock Desert for the annual Burning Man festival. Amid the windy, dusty, tent-strewn desert expanse, where bicycles are the main method of transportation and cellphones barely work, Burning Man belies a vast technological infrastructure.

The tip of the techberg is Heather "CameraGirl" Gallagher. As Burning Man's director of technology, she oversees teams working on physical layout, network engineering, Web development, system integration, and more.

"It's good when people don't know how much technology goes into making Burning Man happen; good technology is tech you don't see," she says. "It's great that people think there's just tents, but this is a city with amazingly complex business needs and operations happening all the time."

Since its modest beginnings on a San Francisco beach 30 years ago, the annual arts and experimental community event has evolved into a weeklong desert city of 67,000. Meanwhile the organization itself has become a global nonprofit that has outreach and regional branches.

Gallagher plans Burning Man's tech needs two years into the future, but she projects as far as five. "The Burning Man event is a very small slice of my very large pizza, although it's the fun, dusty part," says Gallagher. "We have Burning Man all year long, with events and community organizations around the world."

For Burning Man itself, Gallagher heads to the desert in early August to direct a 30-member team. Burning Man regularly maxes out an 80-megabit-per-second microwave connection to its desert community, dubbed Black Rock City. This connection is fed to three radio transceivers that create the onsite network backbone. Bandwidth is distributed through the backbone to approximately 45 internal-department customers and locations, and shared with another 75 or more participant groups that can connect to the network with their own equipment.

"Out here, we're one of the first operations to set up and function as a utility company bringing the Internet and communications to the city," says Gallagher. "My job is to get it to a place where we can go into maintenance mode for the week." Once the week is over, the desert must then be restored to pristine emptiness.

In 1995, Burning Man first used microwave equipment to beam a T1 Internet connection from a motel room in the nearby town of Gerlach. Currently Burning Man gives Gerlach residents free use of a 60-Mb/s connection year-round. But during burn season, that bandwidth gets ramped up to 80 Mb/s to support the construction and setup teams; the media team; the Black Rock Rangers (trained liaisons between the general population and law enforcement); Black Rock City Airport and its FAA-approved temporary runway; a radio station; and emergency services, ticket scanning, and attendee registration. Databases handle work flow, fuel tracking, and billing.

Before committing to new systems, Gallagher needs to ensure they will be viable for several years. "One of the more interesting aspects of my job is talking people out of using technology," says Gallagher. "If your clipboard and pencil are getting it done, let's start there."

Gallagher earned a bachelor's in computer information systems at James Madison University, in Harrisonburg, Va., in 1992, followed by a master's in computer science from George Mason University, in Fairfax, Va., in 1993.

From there, she worked as a telecommunications systems architect and integration consultant. A 1999 move to San Francisco landed her, through friends, among veteran Burning Man attendees. Her first burn came the next year, and in 2001 Gallagher began doing photography for Burning Man, prompting her "CameraGirl" moniker. Soon, she was coordinating the entire photography team and producing the Burning Man calendar. In 2003, she joined Burning Man's IT staff full-time.

For those drawn by the lure of working on Burning Man, Gallagher is currently looking for more Wi-Fi network engineers to support desert operations, as well as year-round assistance from Web and database developers and administrators. **—SUSAN KARLIN**

SUSAN KARLIN

BUILDING 29-STORY VIDEO GAMES

ENCOURAGING GIRLS TO CODE BY GIVING THEM A HUGE CANVAS

Frank Lee has a vision: He pictures a girl looking up at a 29-story office tower in downtown Philadelphia, her face aglow as she watches LEDs across the building's facade light up in clever patterns. He imagines the girl smiling proudly, because that facade is displaying a 29-story video game that she designed and programmed herself.

Lee, cofounder of the game design department at Philadelphia's Drexel University, has devised a literal way for girls to see the big impact they can have in the game industry. At press time, Lee was planning a December 2015 launch of the "world's largest video game" contest for teenage girls in Philadelphia. In partnership with local education group TechGirlz and chapters of the Girl Scouts, the contest will kick off with a series of workshops where students will learn how to code in Python. Then they'll move on to designing games intended for the city's 29-story Cira Centre building, games that will manipulate the office tower's LEDs as if they were pixels on a display screen. Finally, this summer, members of the public will stand on the terrace of a nearby museum and use remote controllers to play the winning games.

The lack of women working in game design prompted this project: "I look at my industry and I'm embarrassed," says Lee. A 2014 industry survey found that women account for only 22 percent of game designers.

Intel has signed on as a sponsor, and the company wants to work with Lee to scale up the initiative. This year's contest will draw its participants from Philadelphia; if the pilot goes well, a regional competition could come next, and then a national contest, says Lee Machen, Intel's director of consumer software. "By that third round, we hope that tech schools for girls will make this part of their curriculum," he says. "Who knows where this will go."

The project fits squarely with Intel's recent mission to increase diversity in the tech industry. At the January 2015 CES technology show, Intel CEO Brian Krzanich announced a US $300 million fund to encourage diversity within the company and in the industry at large. The ambitious effort was a response, in part, to the company's blunder during the 2014 Gamergate controversy, during which Intel initially seemed to side with online communities that were harassing women in the gaming industry.

Machen, whose job includes overseeing Intel's relationships with game developers, says his team aims to make the game industry "a great place to work" for women and underrepresented minorities. While some of their efforts encourage diversity in hiring, Machen says other initiatives must start far earlier to ensure there are plenty of female job candidates. "If there's a pipeline issue, it starts way before people are coming out of college, or even high school," he says.

THE BIG GAME: It's hoped that the chance to use a building-size display, as with this 2013 version of *Tetris*, will inspire teenage girl developers.

The contest also has the support of the real estate company that owns the Cira Centre, a glassy tower covered from top to bottom with a Philips LED display. The company is getting used to Lee's outsize requests: In 2013 he borrowed the facade to play the classic video game *Pong*, and he followed up in 2014 with a mega version of *Tetris*. Lee hopes that the DIY nature of game creation will be more engaging for girls than traditional education efforts have been. Others see similar potential for engagement throughout the broader maker movement: In August last year, Intel's corporate strategist Genevieve Bell told the crowd at a developer conference that the maker movement draws in people who otherwise might not get involved in technology. "It's fun, with a little bit of art, a little bit of whimsy," she said. Make that a big bit of whimsy for Philadelphia.

—ELIZA STRICKLAND

DREXEL UNIVERSITY

DEATHS OF ELEPHANTS

PROPORTION OF ILLEGALLY KILLED ELEPHANTS is estimated by comparing elephant carcasses with population size and natural mortality rates. At levels above the horizontal red line elephant populations would be expected to decline.

SOURCE: CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES OF WILD FAUNA AND FLORA

AFRICAN ELEPHANTS ARE THE WORLD'S LARGEST terrestrial mammals: Adult males can weigh more than 6,000 kilograms, females average about half as much, and newborns about 100 kg. They are sociable, intelligent, proverbially capacious in memory, and eerily aware of death, as they show in their remarkable behavior when they encounter the bones of their ancestors. Although their bones have remained in Africa, their tusks have often ended up in piano keys or in the ivory bric-a-brac you still see sometimes on mantelpieces. • Ancient Egyptians hunted elephants, and Carthaginians used them in wars with Rome until finally elephants became extinct in North Africa, remaining abundant only south of the Sahara. The best available estimate of the continent's maximum carrying capacity (including smaller-size forest elephants) was about 27 million animals at the beginning of the 19th century; their actual number might have been closer to 20 million. Today, though, there are well under 1 million. • Reconstructions of the past ivory trade indicate a fairly steady flow of around 100 metric tons per year until about 1860, and then a fivefold rise just after 1900. The trade plunged during World War I, then rose briefly before another war-induced plunge, after which it resumed its rise, peaking at more than 900 metric tons a year by the late 1980s. I have integrated these fluctuating harvests and come up with aggregate removals of 55,000 metric tons of ivory during the 19th century and at least 40,000 metric tons during the 20th century. • The latter mass translates into the slaughter of at least 12 million elephants. No good systematic estimates of surviving elephants are available before 1970, but the latest continent-wide summary puts the confirmed total at 470,000 in 2006, with another 160,000 animals classed as probable. By the end of 2016 we will know better, when we get the results of the Great Elephant Census, a project funded by Microsoft cofounder Paul G. Allen. The census relies on aerial surveys of about 80 percent of the savanna elephant's range. Some preliminary results are encouraging: After a period of slaughter, Uganda's elephants have bounced back quite strongly.

Other news is deeply discouraging: The number of Mozambique's elephants was halved between 2009 and 2014, to 10,000, and during the same five years more than 85,000 Tanzanian elephants were killed, their total dropping from nearly 110,000 to just 43,000 (the difference is accounted for by an annual 5 percent birth rate). New DNA analyses of large ivory seizures made between 1996 and 2014 have traced some 85 percent of the illegal killing to East Africa, above all in the Selous Game Reserve in southeastern Tanzania, the Niassa Reserve in northern Mozambique, and more recently also in central Tanzania.

Most of the blame rests with China's continuing demand for ivory, much of which gets turned into elaborately kitschy carvings, including statuettes of Mao Zedong, the man responsible for the greatest famine in human history. But this may finally be changing. After three public ceremonies of illegal ivory destruction, including one in Beijing in May 2015, when authorities crushed 660 kg of tusks and carvings, the Chinese government pledged to stop the trade and processing of ivory. We will have to wait for real action. In October 2015, 66-year-old Yang Fenglan was arrested in Tanzania: She was the boss of the biggest smuggling network connecting Africa and China.

And once the slaughter stops, some African regions may face a new problem, evident for years in parts of South Africa: a surfeit of elephants. It is no easy matter to manage expanding numbers of large and potentially destructive animals, especially those living in proximity to farmers and herders. ■

INFOGRAPHIC BY Erik Vrielink

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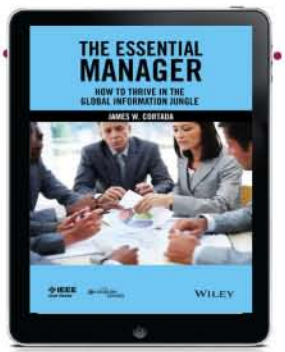

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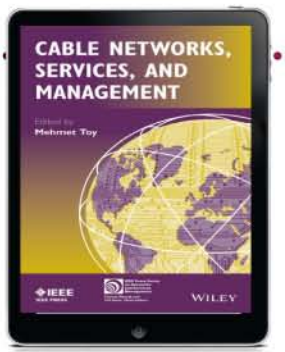

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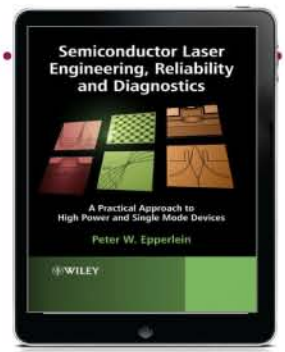

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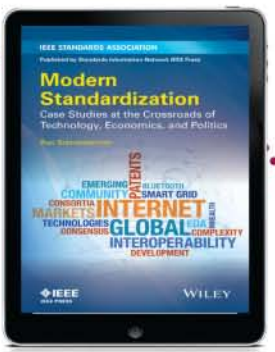

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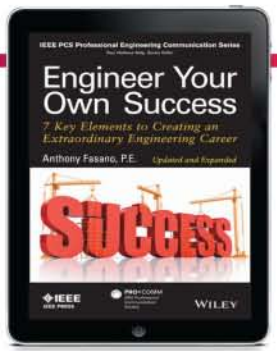

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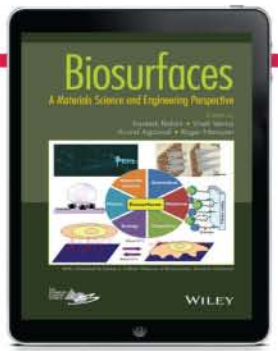

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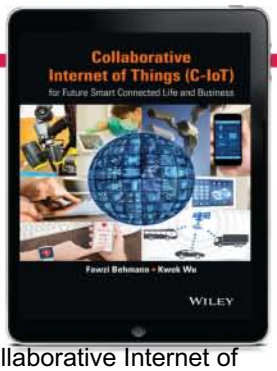

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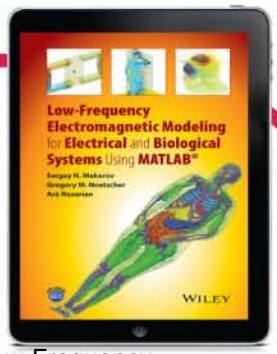

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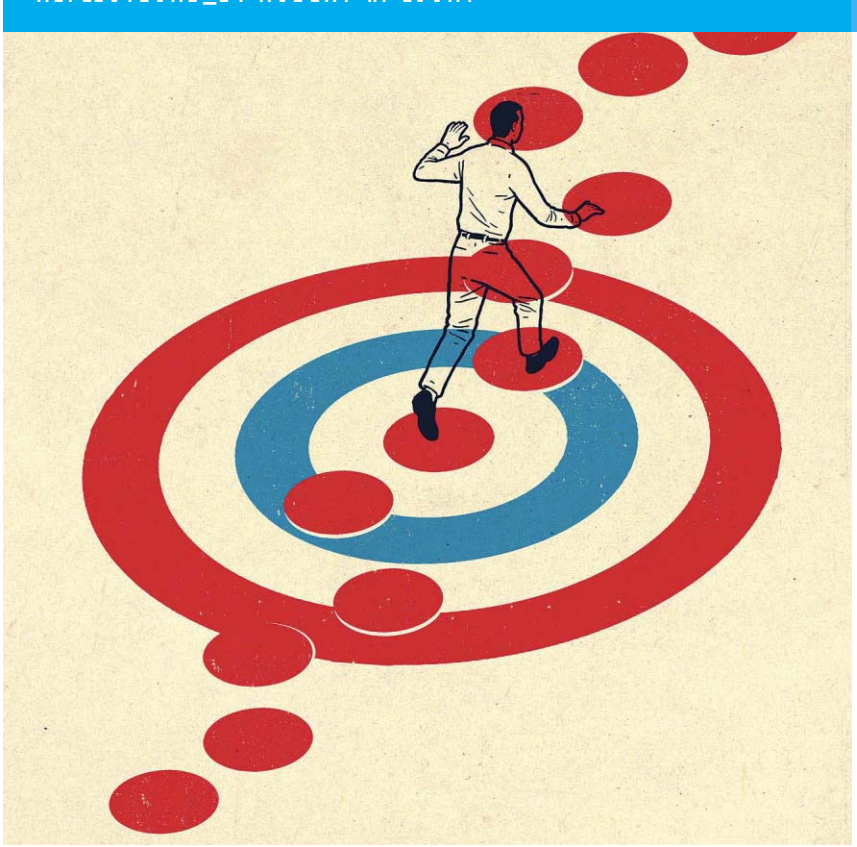

PLANNING FOR GREATNESS

Should we try for great leaps over incremental advances?

KENNETH O. STANLEY AND JOEL LEHMAN have recently published a book titled *Why Greatness Cannot Be Planned: The Myth of the Objective* (Springer, 2015), in which they claim that setting objectives for a project can be self-defeating. They have been motivated to reach this conclusion through experience with an image-morphing website, Picbreeder.org, where users can "breed" new images by successive selection from mutations of earlier images. By this selective process, users starting with random blobs have produced a number of images that strikingly resemble real objects or faces. However, these images are never generated by setting out with the objective of producing a particular image. For example, someone discovers an image that looks very much like a car, but that image doesn't come about by starting with the most "carlike" image possible. Instead, it might be found by further breeding of another user's image that happens to look a little like a car, even though the user who generated that image had something else in mind entirely. Stanley and Lehman go on to argue that, as a general principle in engineering and life itself, greatness cannot be achieved by making incremental progress toward preselected objectives. While I am frankly skeptical of this principle, it is one well worth examining, since our entire engineering culture and environment is based on the setting and achievement of objectives. In education and practice, engineers are problem solvers, and in the obtaining of funding and support it is always necessary to make proposals based on concrete goals.

It also seems to me that most, if not all, of those achievements that we consider the greatest of engineering have been made through the seeking of established objectives. Marconi set out to invent radio, and the inventors of the transistor explicitly sought to invent a solid-state amplifier that could replace vacuum tubes in the telephone network. Jack Kilby set out to implement the first integrated circuit to resolve some very specific problems, and then Gordon Moore established an overriding objective that has guided further development of large-scale integration for more than half a century. The Internet was created under the contracts and program guidance of the Advanced Research Projects Agency (ARPA).

However, the arguments that Stanley and Lehman make are more nuanced than their declarative title might indicate. I am especially interested in their description of greatness as being achieved through a series of stepping-stones, or branch points, none of which—until the end—resemble the final product. This has certainly been true of the image evolution in Picbreeder, but it's also probably the case in great inventions if we look at a longer time frame. For example, at the time that ARPA began developing the Internet, the stepping-stones were already in place: Integrated circuits had enabled computers, and previous studies had proposed packet-switched computer networks. The end product was in sight.

In my own experience as a research manager, I have often felt that the projects with the least-obvious prospects for success were those for which more stepping-stones were needed for achievement of their ambitious goals. In such cases, it may be indeed true that setting objectives is self-defeating.

Stanley and Lehman argue that instead of setting objectives we should seek novelty and simply look to collecting stepping-stones that may be useful to others. Perhaps the researchers in those projects I regarded as unsuccessful did that.

I'm still thinking about all this. ■

ILLUSTRATION BY Dan Page

Top Tech for 2016

BIG AND SMALL, HERE ARE THE TECHNOLOGIES TO WATCH THIS YEAR

Illustrations by **Elias Stein**

PREDICTION IS HARD, as the Danish proverb goes, especially about the future. So the editors of *IEEE Spectrum* have hedged our bets this year by including more topics than usual in our January special report on the coming year's top technology. We include subjects encompassing a geographic span from the bottom of the sea to outer space. The scope is similarly broad, ranging from consumer electronics that you might soon buy and use yourself to multimillion-dollar projects that will affect corporations and countries. • We'll all be hearing more about these tech developments in coming months. But here's your chance to get a jump on everybody else. ▶

ILLUSTRATION ABOVE BY Thirst

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Cyborgs Go for Gold

People with disabilities will use robotics to compete at the first cyborg Olympics

MICHAEL McCLELLAN FLASHES A THUMBS-UP SIGN as he speeds by on a recumbent tricycle, breathing hard but smiling behind dark sunglasses. He pedals along a paved path that loops through a leafy park in Cleveland, passing office workers enjoying alfresco lunches on a warm June day. They chew their sandwiches, oblivious to the guy on the trike. They have no idea that McClellan is paralyzed from the waist down, and that they're watching something extraordinary. It's a training session for one of the world's first competitive cyborg cyclists.

McClellan is preparing for the Cybathlon, the first ever cyborg Olympics, coming to a stadium in Zurich in October 2016. In these games, the competitors will use advanced technologies to compensate for disabilities like paralysis and limb amputation. In the cycling race, for example, paraplegic competitors will use electrical stimulation systems to jolt their paralyzed legs into action; electrodes and muscles will work in tandem to propel their trikes forward.

Yes, the Paralympics already offers athletes with disabilities a forum to showcase their talents. But the Cybathlon's rules and aims are different, explains organizer Robert Riener, a professor at the Swiss Federal Institute of Technology in Zurich (ETH Zurich). The Paralympics bans motorized equipment, but the Cybathlon embraces it.

"It's less about force and speed, and more about control of the body and the device," Riener explains. Instead of celebrating the human body moving under its own power, the cyborg games will celebrate the strength and ingenuity of human-machine collaborations. That's why the Cybathlon's competitors won't be called "athletes" but rather "pilots." Each team consists of a technology group and a pilot, and both will be honored if the team wins a medal.

Riener, who develops robotic rehabilitation systems at ETH Zurich's Sensory-Motor Systems Lab, says the Cybathlon grew out of his frustration with the assistive technologies currently available to people with disabilities. "Most of them are not very useful for the patient," he says. For example, only a quarter of all people with arm amputations use prostheses, Riener says, because the devices are poorly suited to the routine tasks of daily life.

By inviting engineers from academia and industry to build new technologies and train pilots for the Cybathlon, Riener hopes to spur innovation. And to ensure that the resulting gear will be useful beyond the context of the stadium, the Cybathlon's events will incorporate those routine tasks of daily life. In the race for people with powered leg prosthetics, pilots will climb stairs and walk across stepping-stones. During the obstacle course for amputees with powered arm prosthetics, the pilots must slice loaves of bread and open jars of jam, ordinary breakfast rituals that become exasperating when attempted one-handed.

The 80 teams expected at the Cybathlon will arrive in Zurich from all over the world. There will be coverage by the BBC and Japan's NHK, among other major networks, and if the games are a hit, the next Cybathlon could take place in Tokyo in conjunction with the 2020 Summer Olympic Games.

ALL PHOTOGRAPHS BY Nathaniel Welch

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GEARING UP: In a November training session, cyborg cyclist Michael McClellan takes a turn around a Cleveland park.

Ponder that for a moment. The world's premier athletic competition could include the marathon, 400-meter freestyle swimming, the high jump, and also events where participants wrestle the lids off jam jars and climb flights of steps. But at the Cybathlon these seemingly mundane feats will be recognized for what they are: a remarkable synthesis of engineering, dexterity, and pure human grit.

"I LIKE SPEED." McClellan huffs as he speaks, breathing hard after his laps around the park. "That's the reason why I'm in a wheelchair."

While tearing along on a dirt bike in Mexico in 2009, McClellan didn't quite clear an unexpected gully that spanned the road. The bike's impact with the trench's far wall jammed his body against the seat and shattered a vertebra in his lower back. The shards of bone pressed into his spinal cord, making it resemble "a garden hose with a kink in it," McClellan says. His legs weren't injured, but movement commands from his brain can't pass through the damaged spinal nerves to reach them.

How, then, can this paralyzed man cycle through a Cleveland park? The answer comes from a lab in the Louis Stokes Cleveland VA Medical Center, across the street. Neural engineer Ronald Triolo runs the

INVENTOR AND TEST PILOT: Biomedical engineer Ronald Triolo developed the nerve stimulator that activates Michael McClellan's paralyzed legs.

Advanced Platform Technology Center there (he's also a professor at nearby Case Western Reserve University). Triolo uses a technique called functional electrical stimulation (FES) to help people with spinal cord injuries, deploying pulses of electricity to activate the leg nerves that control otherwise dormant muscles. These jolts crudely mimic the electrical signals that would normally travel from the brain and through the spinal cord to reach the peripheral nerves.

Many rehab clinics have simple FES systems with surface electrodes that stick to the user's legs, stimulating the nerve faintly by transmitting an electric pulse through skin and flesh in the correct general direction. But this scheme doesn't provide precise control, so Triolo has pioneered the use of electrode "cuffs" that are surgically implanted and wrap around the nerves themselves.

Each tiny cuff of silicone rubber has four embedded platinum contacts that touch different spots on the surface of a nerve bundle, allowing stimulation of specific nerve fibers in intricate patterns. The current arrives at the electrodes through thin wires connected to an implanted pulse generator that sits inside the abdomen. Triolo designs stimulation patterns in his computer and sends the commands to the pulse generator via a wireless link. "All the changes to the timing and patterns of stimulation are made in software, so none of the implanted components have to be replaced," he explains. An external device also transmits energy via radio frequency to recharge the pulse generator, so there's no battery to swap out.

Through two decades of experiments, Triolo has developed stimulation patterns that enable paraplegics to do leg lifts, rise from their chairs, stand upright and support their weight on their legs, and even take small steps forward while maintaining balance with a walker. He's now working on nerve cuffs with additional embedded contacts that will let him program more sophisticated stimulation patterns. Ultimately, he wants to get people like McClellan walking normally again.

McClellan heard about Triolo's experiments in 2011 from a friend at a rehab clinic near his home in California and immediately volunteered. "I didn't think twice about it," he says. "I was all in." During an 11-hour procedure, surgeons implanted 10 electrodes in his legs and hips: a cuff around each of his two femoral nerves, allowing control of discrete muscle fibers in his quadriceps, and eight simpler single-contact electrodes that activate the nerves in his gluteal muscles and hamstrings. After six months of healing, McClellan came back to Cleveland to have his stimulator turned on for the first time.

He didn't jump to his feet right away; first a team of physical therapists put him through eight weeks of grueling strength training. He spent hours lying in bed as the stimulator energized his nerves and caused his legs to lift, hoisting small weights into the air. Though McClellan's muscles were triggered by externally generated pulses rather than his brain, the result was nevertheless the same: Muscle mass increased. In between these training sessions, the engineers tested different stimulation patterns on him, experimenting with the amount of current and the timing of the electric pulses. Then they built a small external controller with a few buttons, and programmed each button to trigger a stimulation pattern for a specific movement, such as lifting his left leg or rising from a chair.

Finally, the clinicians and engineers agreed that he was ready to stand. With the whole team gathered in a rehab room, McClellan punched the "stand"

MATTER OF FACT

In the early 1780s, Italian anatomist Luigi Galvani discovered that he could make a dead frog's leg muscles contract by sending an electric current through a nerve.

button, and his paralyzed legs hoisted him upright. Asked to describe that moment, McClellan pauses.

"Have you ever seen a dog do a big stretch with its paws out in front of it?" he says at last. "You see it and you think, 'That's gotta feel good.' " The researchers who watched him extend his nearly 2-meter (6-foot-4-inch) frame must have thought the same thing.

TRIOLO ORIGINALLY CONSIDERED the Cybathlon a bad idea. "What we really need is cooperation and international groups working together, not a competition," he remembers thinking. But he soon reconsidered, deciding that the games could push the technology forward by bringing researchers together in a spirit of friendly rivalry. Intrigued by the cycling event, he asked several of his research volunteers, including McClellan, if they'd help him adapt his stimulation system for cycling, and got to work on new patterns that would cause a paralyzed cyclist's leg muscles to push on bike pedals.

Now, in this early-summer training session in the leafy Cleveland park, a rejiggered system is getting its first tryout. The engineers have already spent hours with McClellan on a stationary bike in the lab, fine-tuning the stimulation pattern. In the park, though, they're discovering the limitations of their current setup.

As McClellan pedals up a subtle rise in the path, the trike naturally slows down, but the timing of the muscle-stimulation pulses in his legs doesn't vary. That's a problem, because McClellan gets out of sync, with his leg muscles pushing against the pedals at the wrong points in their revolutions. McClellan tries to compensate by using a few muscles he can control around his hips to bear down at the proper moments. He tries to pull each hip up "just enough to get the pedal around that 12 o'clock point, to get it ready for that power stroke," he explains.

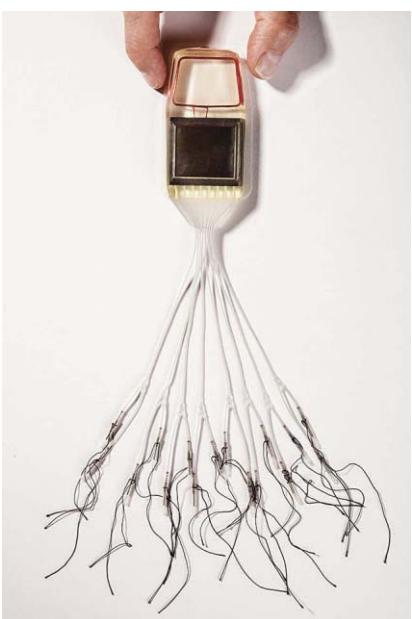
Triolo has a plan to improve the translation of McClellan's muscle contractions into cycling forces. He'll spend the next few months adding position sensors to the pedals that will send information to McClellan's implanted pulse generator, signaling each moment when a pedal is ready for its power stroke. "The trick is getting the technology and the biology to work together as a single unit," Triolo says.

While McClellan's first task as a pilot is pressing the button on his controller that triggers the cycling stimulation pattern, that's hardly the end of his involvement. His muscles must respond to the electrical stimulation and do the actual work, and if they're not in good condition his performance will quickly decline. Stimulating a nerve once muscle fatigue has set in yields diminishing returns, Triolo says.

To improve both strength and endurance, McClellan will keep doing leg lifts at the gym and hopes to get a recumbent trike to ride in his neighborhood. He's eager to train, and not only for the Cybathlon. He's also thinking of his future, and dreaming of stem-cell therapies that could one day repair damaged spinal nerves. Such treatments are just laboratory experiments today, but if they become medical realities McClellan plans to be strong enough to benefit. "I want to have healthy muscles and good bone density so I can participate in anything that comes along," he says.

Next October, if all goes well with his training, McClellan's healthy muscles will whiz him around the 750-meter track in Zurich. If his body and his technology work together to speed his bike across the finish line first, he'll have one more thing to do. He'll press the "stand" button on his controller and rise to his feet to receive the gold medal.

He may take the podium as a modern marvel, but McClellan says the process of becoming a cyborg Olympian has only whetted his appetite for more. "My enthusiasm comes from realizing: This is just the beginning of what we can do," he says. —ELIZA STRICKLAND



OUTSIDE AND IN: The stimulator's patterns are selected using external controllers, and its programming is changed via an external transmitter [left]. The implanted pulse generator sends current through thin wires that stimulate the nerves [right].

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Can HPE's "The Machine" Deliver?

A 320-terabyte prototype, expected this year, will showcase the company's bid to reinvent computing

HP NEVER SHIED AWAY from big names for its computers. There are high-performance servers named Apollo and optimized computing systems called Moonshot. And then there's The Machine.

When Hewlett-Packard Co.—now split in two—announced The Machine in Las Vegas in 2014, it presented the project as a near-complete overhaul of traditional computer architecture. Gone were the CPU-centric architecture, the slow copper communications, and the messy hierarchy of traditional memory. In their place, specialized computing cores, speedy light-carrying photonic connections, and a massive store of dense, energy-efficient memristor memory. The resulting computer, its designers say, will be efficient enough to manipulate petabyte-scale data sets in an unprecedented fashion, expanding what companies and scientists can accomplish in areas such as graph theory, predictive analytics, and deep learning in a way that could improve our daily lives.

There is nothing small about what HP promised. Now the question is what will come of the initial claims. It seems we'll soon get a glimpse of the vision, realized in hardware; Hewlett Packard Labs (formerly HP Labs) says it hopes to unveil its first large-scale prototype of The Machine this year. The project is now part of Hewlett Packard Enterprise (HPE), which focuses on corporate computing (the second HP spin-off, HP Inc., sells PCs and printers).

That initial computer is a whopper by modern standards: It's expected to be about the size of a server rack, with 320 terabytes of memory and more than 2,500 CPU cores. But one key Machine component will be missing: the memristor.

The device, one of four fundamental circuit elements, was developed at HP Labs. HP touted it as an energy-efficient replacement for DRAM, the workhorse memory that sits close to CPUs. Like flash, memristors can also act as nonvolatile storage, retaining their data even when powered down.

HP Labs looked at ways to capitalize on these properties after the memristor was announced in 2008. In the end, the device became a key component of a larger overhaul the company calls Memory-Driven Computing. Current computers have different forms of memory, each with different advantages when it comes to cost, power consumption, and speed. Memristors with various capabilities, the thinking went, could eventually replace them all.

In his first public talk about The Machine, in 2014, the then HP Labs director Martin Fink outlined a picture of what this might look like: a computer server with as much as 160 petabytes of data—roughly five times what the Large Hadron Collider produces in the course of a year—all accessible in less than 250 nanoseconds. Such capacity would be huge, says Richard Fichera, an analyst at Forrester Research, and the access time on the order of 1,000 times as fast as can be done today. But memristors have had teething pains. Although HP previously showed off wafers containing memristors, a commercial offering has yet to emerge.

When The Machine's first prototype arrives, it will carry energy-hungry DRAM in their place. The memory will be a stand-in, the team says, that can be used to emulate later hardware and move development forward. "Everything the Machine team is doing is designed to get us to working, useful

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Machine prototypes as quickly as possible," the group wrote to *IEEE Spectrum*. "We still believe memristors are the best candidate, but rather than waiting until memristors are ready before making prototype Machines, we'll use more conventional memory to learn about memory fabrics and how operating systems, analytics, and applications should change now rather than waiting." Memristors, in principle, will be slotted in later, although no time frame has been given for when that might occur.

Grand announcements about products that are still years away are rare in the computer industry. "We don't need to talk about stuff five years from now," Juan Loaiza, Oracle senior vice president for systems technology, told *Bloomberg Businessweek*.

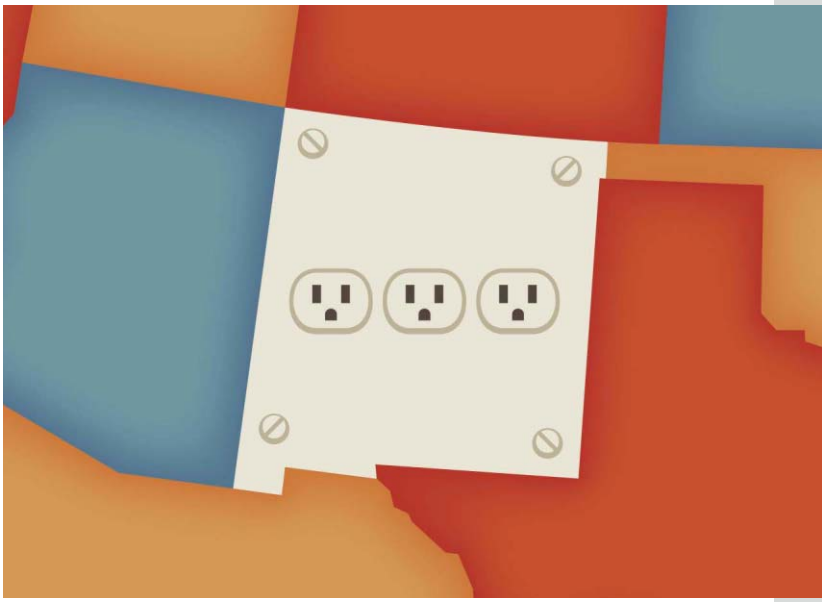
HPE says the project will evolve, with hardware and software building upon one another in a "virtuous cycle." Commercial offerings, ranging from credit-card size to supercomputer scale are targeted for 2020, but components of The Machine will be marketed as they become available.

"As a research vehicle, I think it's a great idea. I just think they sort of painted themselves into a corner with a lot of early and aggressive hype," says Forrester's Fichera, who worked on server strategy at HP. "It's going to be a real challenge for them to pull off some of the things they're talking about."

The memristor could have a big impact on success, Fichera says, as it is the one piece of Machine hardware exclusive to the company. "If they could build a huge server with a huge memory space and somehow allow these individual nodes to share that memory more efficiently, that could be a very advantageous architecture," he said. "Unfortunately anyone else who wants to chase that same goal is going to have all of the same components to work with."

But perhaps HPE, which sells servers, will go a different way. Last year, Intel and Micron announced a speedy new form of nonvolatile memory called 3D XPoint aimed to ship this year. Jim Handy, an analyst at Objective Analysis, says he suspects those companies could well have convinced then HP that their memory is "a better or more timely solution."

If that's true, other companies will have access to that same memory technology. With the ample heads-up from HP in 2014, they too could be lacing up their racing shoes. —RACHEL COURTLAND



The U.S. May Finally Get a Unified Power Grid

The long-delayed Tres Amigas superstation aims to link North America's three main electricity networks

IT IS A DECADES-OLD DREAM: a single, vast North American electric grid, from the Atlantic to the Pacific, from Mexico to the Arctic Circle. Such a continent-wide supergrid would let officials transmit the tens of gigawatts of wind-generated power from the Great Plains to cities on both coasts. It would let Pacific Northwest hydropower flow to Chicago and let Texas wind power find its way to Massachusetts, Mississippi, and Montana. The benefits, measured in financial and reliability terms, would be fantastic. And yet despite many studies and even several attempts to create such a grid, it has never been achieved. The technology and the political will have been lacking.

This year, though, engineers will make a major stride in the former. An ambitious project known as Tres Amigas, eight years in the making, is finally getting under way. Eventually it will link the three largest North American grids: the Eastern Interconnection, the Western Interconnection, and the Texas Interconnection, which together cover the lower 48 states plus 8 Canadian provinces. Tres Amigas, located in eastern New Mexico, where the three grids converge, will be a transmission "superstation," able to transfer up to

MATTER OF FACT

A Proto-Supergrid: In 1918, engineer William Spencer Murray proposed a "Superpower Zone" of transmission lines and power plants from Washington, D.C., to Boston.

20 gigawatts of electricity in almost any direction.

Last November, construction workers began building the first piece of the first phase of the project: a 56-kilometer transmission line to connect three new wind farms to the superstation site and then to the Blackwater substation, which connects to the Western grid. The 345-kilovolt line is scheduled to be electrified by the end of this year; Blackwater will also be upgraded to handle the added capacity of up to 500 megawatts of wind power.

The ultimate plan, with an estimated price tag of US $1.6 billion, is to construct three more lines to substations in Texas, one of which connects to the Texas grid (usually referred to as ERCOT, the acronym for the entity that runs it, the Electric Reliability Council of Texas), and the other two connecting to the Eastern grid.

The four sets of transmission lines would converge at Tres Amigas, a 58-square-kilometer site where the company will install high-voltage DC converters for converting AC to DC and back again, plus a modest 5 MW of storage for regulating voltage and frequency. As more partners sign on, additional converters and storage can be added. Other plans call for an electricity-market hub to let traders take advantage of the differences in electricity prices between regions. On 10 August 2015, for instance, the price difference between ERCOT and the Western grid hit $2,331.54 per megawatt-hour. Capitalizing on such disparities should generally lower rates for customers and stimulate more investment.

Having a high-voltage DC node that connects existing AC networks—a configuration called an HVDC overlay—will make the entire grid more stable and responsive to outages and faults, says Tres Amigas CEO Philip G. Harris. "Very large integrated AC systems tend to get wobbly," he says. "An HVDC overlay, with its ability to move a lot of power quickly, will provide a huge reliability enhancement as the electricity grid grows." Grid operators in Western Europe are already installing or planning a number of these HVDC overlays, he adds. China and India are going even further, installing transmission grids based entirely on HVDC.

A few links already exist between the main U.S. grids, such as the 200-MW HVDC converter station near Sidney, Neb., which connects the Eastern and Western grids, and the 220-MW HVDC station outside Oklaunion, Texas, which connects the Texas and Eastern grids. But Tres Amigas would bring together all three grids in one place and at much higher power levels.

Harris came up with the idea for Tres Amigas shortly after he retired as CEO of PJM, a regional grid and wholesale electricity market spanning the Middle Atlantic United States. In 2008, he says, "we drew up our plan, and within a few months we had several million dollars lined up." Funding dried up with the global financial crisis. "The utilities told us they wanted Tres Amigas," Harris says, but investors accustomed to funding electricity generation or transmission projects "had trouble trying to fit it in a 'generation or transmission' box."

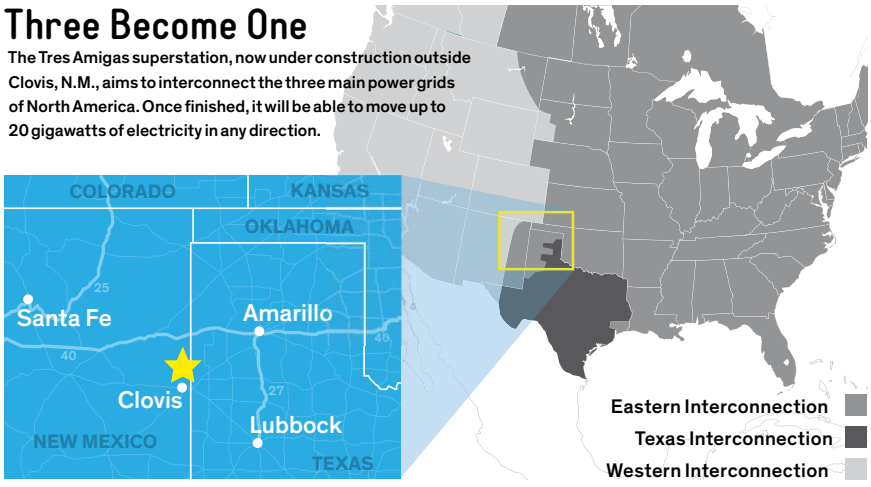
So Harris and his partners did everything except build the superstation: They completed the system assessments, lined up suppliers, leased land for the superstation, secured the rights of way, won regulatory approvals. The original timeline called for completion by 2013 but has been revised repeatedly. Last July, in fact, Excel Energy terminated an agreement with Tres Amigas that would have allowed the superstation to connect to the Eastern grid, citing missed deadlines going back several years. Harris is confident that the agreement will be revived once his group updates the interconnection studies to Tres Amigas.

The superstation's design has also been revised. Current plans call for a more or less traditional power transmission node. But early schematics depicted a much more advanced concept: a superstation laid out in a triangular hub, with an HVDC converter station at each point and underground superconducting DC cables connecting those points.

"We called it the flux capacitor," Andre Canelhas, a London-based HVDC expert who helped design Tres Amigas, says with a laugh, referring to the three-legged time-travel device from the sci-fi movie *Back to the Future*. "But in a sense, we *are* bringing the future to the present, where life is going to get a lot more interesting as renewables replace fossil-fuel plants, and we'll need to move large blocks of power to where generation is suddenly insufficient. A project like Tres Amigas will make us evolve the way we need to evolve." —JEAN KUMAGAI

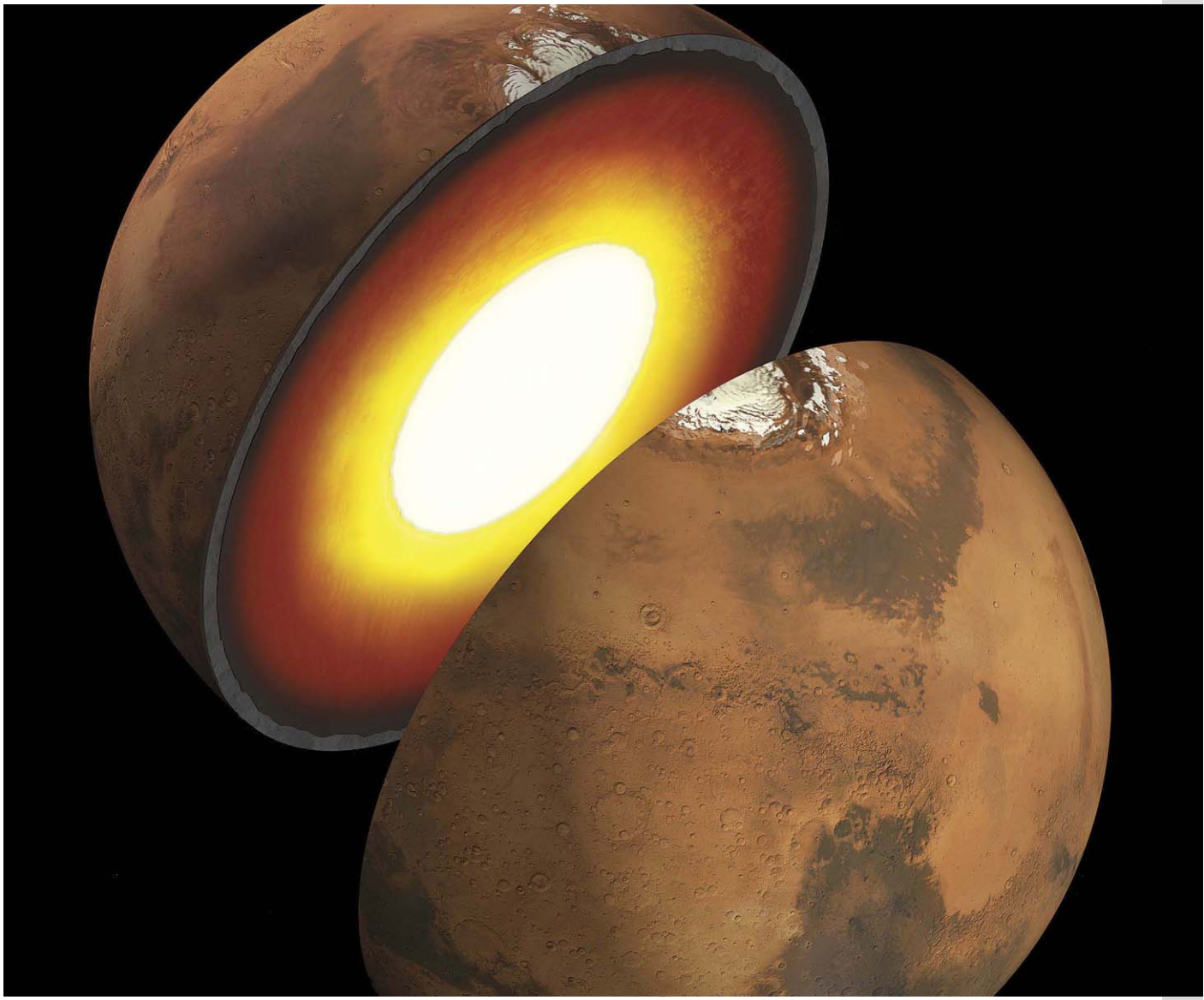
Three Become One

The Tres Amigas superstation, now under construction outside Clovis, N.M., aims to interconnect the three main power grids of North America. Once finished, it will be able to move up to 20 gigawatts of electricity in any direction.



SOURCE: NORTH AMERICAN RELIABILITY CORP.

ILLUSTRATION BY Erik Vrielink



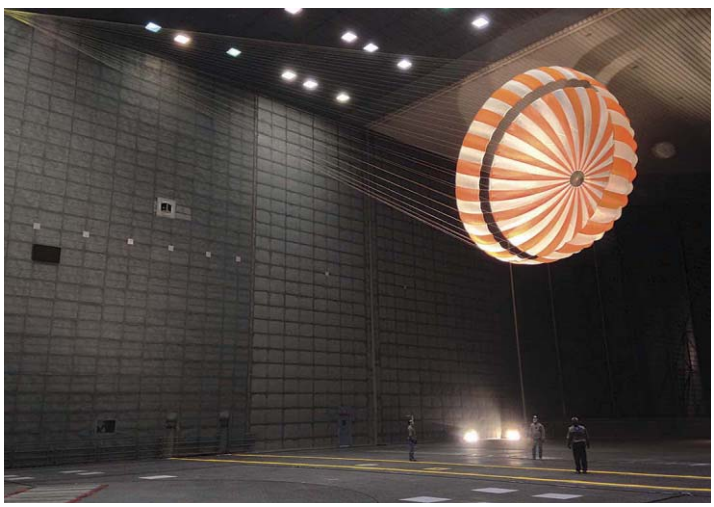
JPL-CALTECH/NASA

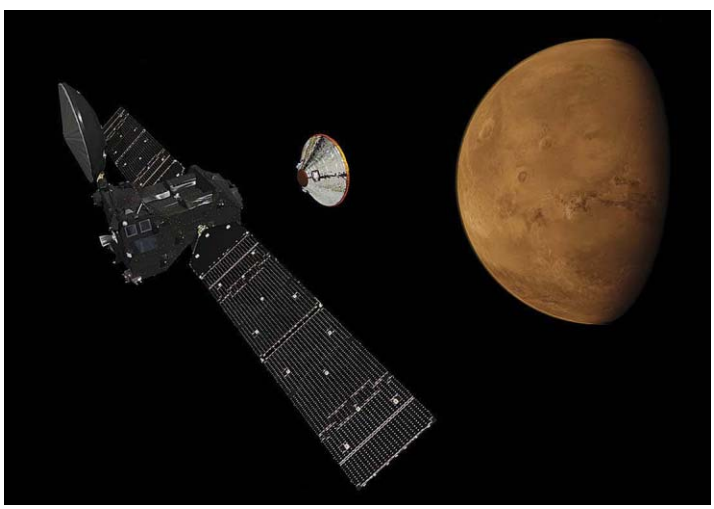
Studying Mars, Inside and Out

Probes will investigate the atmosphere and interior of the Red Planet

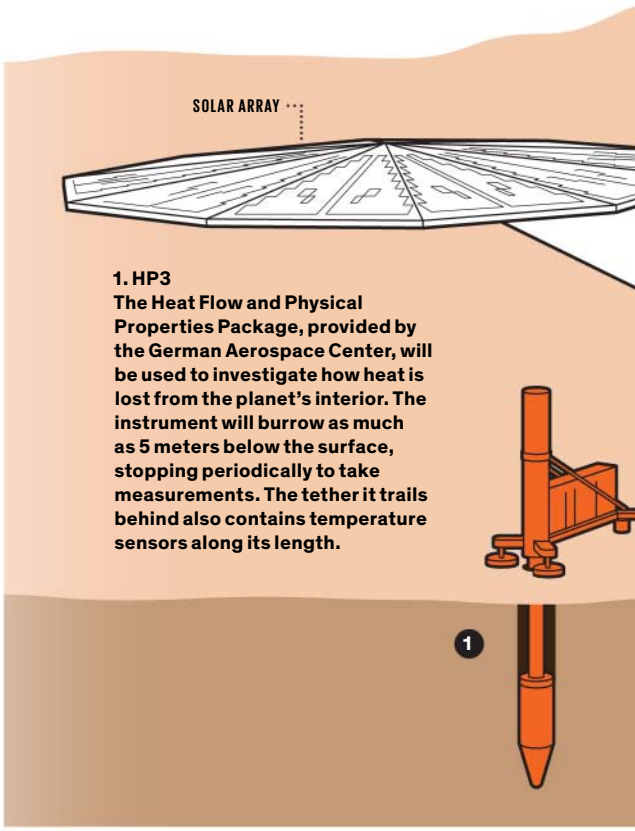
WHEN THE TWIN VIKING LANDERS touched down on Mars in 1976, each carried a seismometer. But the sensors turned up little in the way of planetary vibrations. One seismometer failed to deploy properly; the other, mounted like its counterpart on the lander's deck, picked up mostly wind.

Forty years later, the seismic study of Mars is poised for a second act with NASA's InSight lander. As *IEEE Spectrum* went to press, the InSight team was still working to resolve a problem with the spacecraft's seismometer package but aimed to keep to a





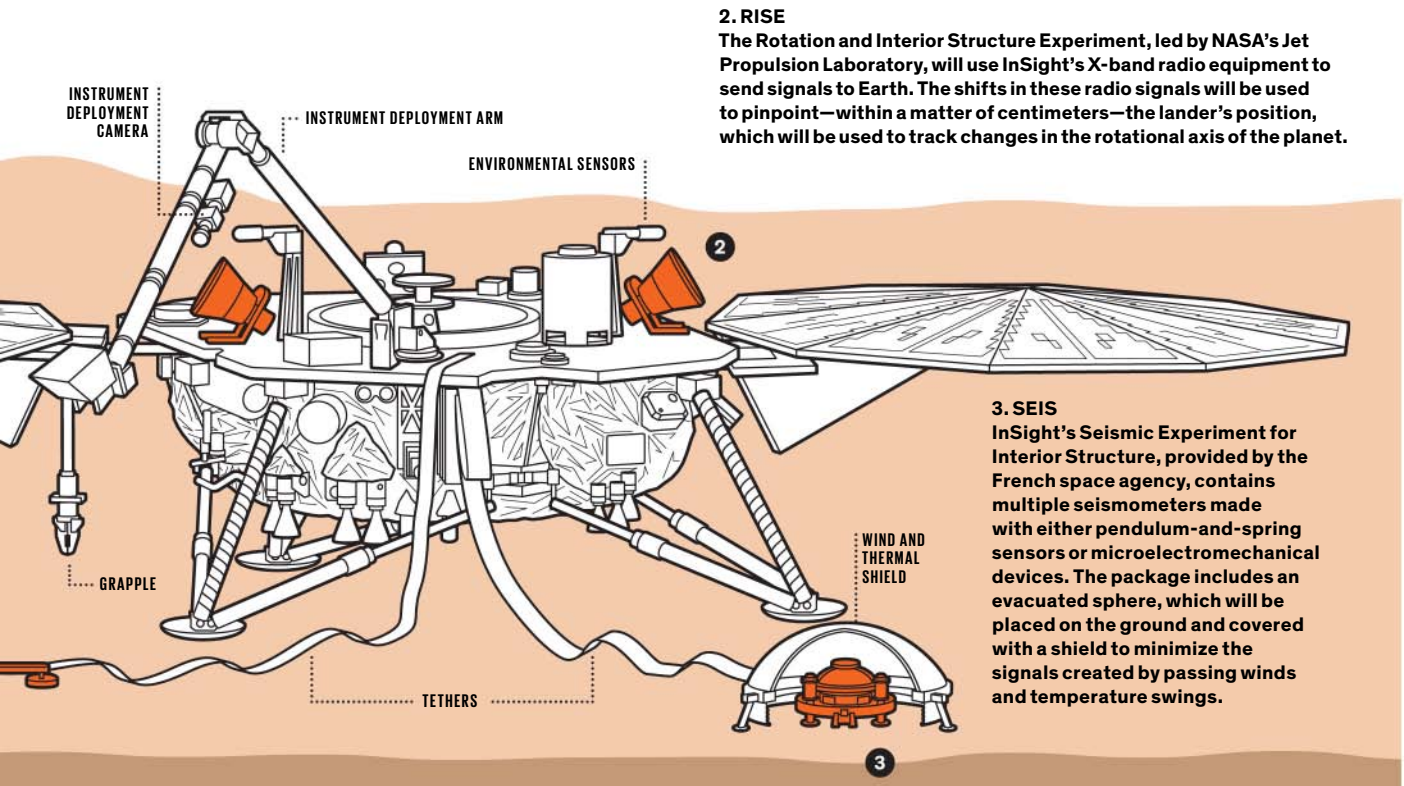
MORE FOR MARS: The solar arrays of NASA's InSight lander are on display in a Lockheed Martin clean room in Denver [top]. Parachute testing [middle] for the mission is done at NASA Ames Research Center, in Moffett Field, Calif. An illustration [bottom] shows the separation of the ExoMars 2016 orbiter and landing demonstrator.



scheduled March launch from Vandenberg Air Force Base, in California. If all goes as planned, the spacecraft will reach the Martian surface in September, where it will use seismometers to listen for quakes created as the planet slowly cools and contracts, vibrations rippling out from colliding meteoroids, and other sources of motion. Researchers hope to use the sound waves to build a picture of the interior of the planet, much as signals generated in a sonogram are used to image the body.

To save effort and cost, InSight copies many features of NASA's solar-powered Phoenix lander, which reached Mars in 2008. The spacecraft, which is being built by U.S. contractor Lockheed Martin, has a strong international component. France, Germany, and other countries contributed roughly US $100 million in the form of scientific experiments, says Bruce Banerdt, a planetary geologist at NASA's Jet Propulsion Laboratory, in Pasadena,

FROM TOP: LOCKHEED MARTIN/JPL-CALTECH/NASA (2); ATG MEDIALAB/ESA



2. RISE
The Rotation and Interior Structure Experiment, led by NASA's Jet Propulsion Laboratory, will use InSight's X-band radio equipment to send signals to Earth. The shifts in these radio signals will be used to pinpoint—within a matter of centimeters—the lander's position, which will be used to track changes in the rotational axis of the planet.

3. SEIS
InSight's Seismic Experiment for Interior Structure, provided by the French space agency, contains multiple seismometers made with either pendulum-and-spring sensors or microelectromechanical devices. The package includes an evacuated sphere, which will be placed on the ground and covered with a shield to minimize the signals created by passing winds and temperature swings.

INSIDE MARS

InSight copies many features of NASA's 2008 Phoenix lander, including a robotic arm that will be used to place instruments on the Martian surface.

Calif., and InSight's principal investigator. The U.S. portion, capped at $425 million in 2010 dollars, covers the cost of the spacecraft and two years of operation on the Martian surface (the launch is extra).

The French space agency, CNES, led the development of InSight's seismometers, with contributions from institutions in several countries. The instrument is 1,000 times as sensitive as those carried by the Viking landers—even more at some frequency ranges, says payload leader Philippe Lognonné of the Institut de Physique du Globe de Paris. At the same time, the sensor is built to be rugged enough to withstand the wide swings in Mars surface temperatures for at least two Earth years.

After landing, InSight will use its robotic arm to remove the instrument from the deck of the spacecraft and set it on the ground. An aluminum dome will then be placed on top to reduce the effect of wind and temperature swings on the data it collects. The arm will also deploy a heat probe, provided by the German Aerospace Center, to measure heat loss from the interior of the planet. InSight will track temperatures as an electromechanical hammer knocks the probe down a millimeter or so at a time to an ultimate depth of as much as 5 meters. The process, which will pause periodically to take measurements, is expected to take several weeks. A third experiment will remain on the spacecraft and measure variations in radio signals sent between the spacecraft and Earth to track the slow wobble of the planet's rotational axis, which is influenced by its internal structure.

Modern seismic studies of Earth's interior rely on many distributed sensors. Researchers initially thought that a proper study of the Martian interior would also require a network of sensors scattered around the planet, Banerdt says. But he and his colleagues eventually concluded that with modern signal analysis techniques, they should be able to extract meaningful information about the planet's interior using seismometers installed at a single site—a much cheaper prospect.

ILLUSTRATION BY James Provost

MATTER OF FACT
As many as 12 Mars spacecraft could be in operation during 2016.

The trick, Banerdt says, comes from the fact that a single quake creates multiple signals that wrap both ways around the planet. The arrival times of these signals can be used to deduce the location of the source of the vibrations and the speed at which they move. Such information will help planetary geologists improve estimates of the thickness of the planet's crust and the composition of its mantle. The measurements made with the spacecraft's radio experiment, which will add to a body of data collected by previous Martian landers, will refine the picture of the planet's core.

InSight's results, Banerdt says, will not only illuminate the internal structure of Mars but also help scientists understand how rocky planets in general form and change over the first tens of millions of years of their lives. "We actually proposed this not as a Mars mission but as a solar system mission," Banerdt says. "We're trying to understand how planets are built [and] why Venus, Earth, and Mars are so different."

Mars, he says, is a good window on the early solar system. The planet is an almost Earth—smaller than our own planet yet large enough to have experienced similar temperatures and pressures as Earth did when it formed about 4.5 billion years ago. But while geological processes have erased much of the evidence of what Earth looked like early on, Mars has remained largely inactive, so its early state has been preserved.

InSight is one of five spacecraft that could reach the Red Planet this year. InSight's rocket will also carry a pair of CubeSats, for a mission dubbed Mars Cube One, which will assist in relaying signals during InSight's entry, descent, and landing. The two spacecraft, more or less briefcase-size when stowed, will be the first CubeSats sent beyond Earth orbit.

Also aiming for a March launch is the first of two ExoMars missions by the European Space Agency and Russia. It will send the Trace Gas Orbiter to hunt for the spectral signatures of gases in the Martian atmosphere such as methane, which could have a biological or geological source. The mission will also carry Schiaparelli, a spacecraft designed to test landing technology. It would pave the way for the ExoMars rover, targeted for launch in 2018.

—RACHEL COURTLAND

JPL-CALTECH/NASA

COMPARATIVE PLANETOLOGY

EARTH HAS MOVING PLATES, which raise mountains and create new oceans. Mars is awfully quiet by comparison. The quakes that planetary scientists expect to see on the Red Planet are created by slow contraction and the press of heavy formations on the surface, explains Véronique Dehant of the Royal Observatory of Belgium.

The differences between the two planets go deep. Iron circulating in Earth's liquid core creates a global magnetic field, which protects the atmosphere. Mars seems to have once had such a field, too, but it disappeared billions of years ago.

Although that field was lost, data collected on how Mars stretches due to the tidal tug of the sun, along with the way it spins, suggest the planet's core remains at least partly liquid. At some point in its history, Dehant says, the Martian core became too cool to drive circulation through convection; it is now thought to be losing heat through the less efficient process of conduction. "[The liquid state of the core] still needs to be verified," says Dehant, a coinvestigator on InSight's radio-frequency experiment RISE. InSight should be able to reduce uncertainty in the core's diameter by a factor of 10, she adds, which will help pin down its properties. —*R.C.*

MATTER OF FACT

On 15 August 1977, SETI researcher Jerry R. Ehman detected an intriguing signal that appeared to come from somewhere in space. His so-called "Wow!" signal still remains a mystery.

$100 Million SETI Initiative Starts Listening for E.T.

Armed with new gear, astronomers seek radio and laser signals from other worlds

THE SEARCH FOR EXTRATERRESTRIAL intelligence—SETI—has a checkered history, and even its most ardent proponents accept that positive results are unlikely anytime soon. So it's no wonder that SETI researchers often struggle to find funding. But last year the Russian billionaire Yuri Milner offered to support SETI efforts over the next 10 years with US $100 million. The first radio observations, through a program called Breakthrough Listen, will be made sometime in the next few months. And one of the early targets may be a star system that has already shown suggestions of possibly being the home of a technologically advanced alien civilization. While the chances for actually picking up signals from an E.T. remain slim, the adventure will surely be fun to watch as it unfolds this year.

The Breakthrough Listen initiative was announced in July last year, after Milner had his new SETI-funding program organized under the umbrella of the Breakthrough Prize Foundation, which he had launched in 2013 with additional contributions from Google cofounder Sergey Brin and Facebook cofounder Mark Zuckerberg. There are two components to the initiative: Breakthrough Listen will boost efforts to detect signals from extraterrestrial civilizations, and Breakthrough Message will explore sending signals in the other direction.

"Assume you're a billionaire and you're interested in SETI. You could get the SETI Institute or you could get us," says Andrew Siemion, director of the Berkeley SETI Research Center and one of the leaders of Breakthrough Listen, referring to his group's counterpart on the other side of San Francisco Bay, the SETI Institute in Mountain View, Calif. "It just so happens that it was us."

Dan Werthimer, chief scientist of the well-known SETI@home project and another of the leaders of Breakthrough Listen, notes that the fiscal shot in the arm is coming at just the right time. "NASA recently decided that they will no longer fund SETI experiments," says Werthimer. "So we are very fortunate." He, Siemion, and their SETI colleagues at Berkeley had been operating on a shoestring. With the Breakthough Listen funding, Siemion says, "the faucet is running—we're working full steam."

Some of the money is for observation time, beginning in February, on the Robert C. Byrd Green Bank Telescope in West Virginia. Observations will also take place on "the Dish," the giant radio telescope at the Parkes Observatory, near Parkes, Australia, starting in October. And some money will go toward "optical SETI," which is to be carried out using a 2.4-meter-diameter telescope at the University of California's Lick Observatory, just east of San Jose. The researchers are also building better radio receiving equipment. "There's a huge amount of money going to the development of instrumentation that we bring to these telescopes," says Werthimer.

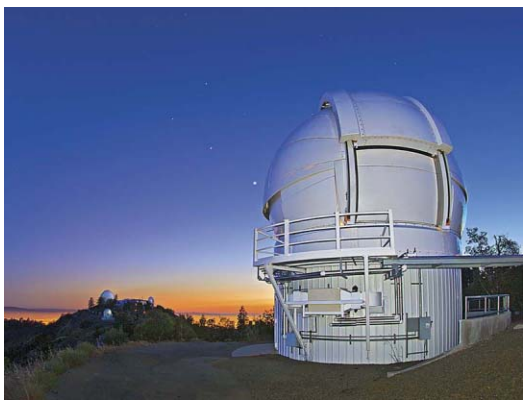
Perhaps most exciting will be Breakthrough Listen's observations of a star system called KIC 8462852, which came to the attention of researchers last year after amateur planet hunters examining data from the Kepler space telescope noticed that the light from this star varies in a way that is downright bizarre. At times the amount of light diminishes by as much as 22 percent. Yet the dramatic dips in brightness are not periodic,

as would be expected were the cause an orbiting exoplanet. "You can come up with [natural] explanations, but they seem contrived," says Siemion.

One intriguing possibility, much discussed in the media last fall, is that this star is surrounded by artifacts of an alien civilization, perhaps something akin to a "Dyson sphere," the hypothetical construction an advanced civilization might erect in space to harvest light from its parent star (named after the originator of the concept, physicist Freeman Dyson). Initial efforts by researchers at the SETI Institute using the Allen Telescope Array have, however, failed to turn up any evidence of intelligent life around this star.

Hoping to explore that wild idea, Siemion and his colleagues in early 2015 had submitted various proposals for observation time on the Green Bank telescope. Breakthrough Listen will make further radio observations of this star possible even without any other funding. "One way or another," says Siemion, "come March, we'll be observing this star."

—DAVID SCHNEIDER



THE FINAL FRONTIER: As part of the Breakthrough Listen initiative, astronomers will search for optical signals using a 2.4-meter telescope at the Lick Observatory [top], thanks to funding from Russian billionaire Yuri Milner [bottom].

Don't Expect Encrypted E-mail in 2016

Despite big promises, Yahoo and Google probably won't champion end-to-end encryption

LAST MARCH ALEX STAMOS, then Yahoo's head of information security, showed off prototype software for encrypting sensitive e-mail messages. The new tool, which Stamos said could be ready for deployment by the start of 2016, featured "end-to-end" encryption, meaning that even Yahoo itself wouldn't be able to decrypt messages stored on its servers.

Yahoo promised to make such encryption easy to use, building on open-source software for end-to-end e-mail encryption that Google has been developing. (Google's software implements a standard called OpenPGP, based on an encryption system that Phil Zimmerman created in 1991: Pretty Good Privacy, or PGP.)

If Yahoo and Google were to throw their market weight—not to mention their substantial developer resources—behind end-to-end e-mail encryption this year, it would no doubt displease the many government authorities who claim this technology is rendering them unable to eavesdrop on bad guys' electronic communications—or "going dark" as they call it.

James Comey, director of the Federal Bureau of Investigation, summarized those sentiments in July when he told the Senate Judiciary Committee that "we have on a new scale seen mainstream products and services designed in a way that gives users sole control over access to their data." He pointed to the central role of tech companies, saying, "We would like to emphasize that the Going Dark problem is, at base, one of technological choices and capability."

The implication of Comey's statement was clear: If companies were forbidden by law from offering such privacy protections, the products and services Comey alluded to would have to be shut down—at least in the United States. But it's unlikely that the U.S. government will do that anytime soon. Indeed, the Obama administration signaled in October that it would not ask tech companies to build back doors into their encryption products, given the strong possibility that weakening security in this way would enable criminal hackers and malicious foreign agents to compromise even more systems than they are already doing.

Such concerns aren't so strong on the other side of the Atlantic, though. In particular, U.K. prime minister David Cameron indicated

TOP: LAURIE HATCH; BOTTOM: NIKLAS HALLEN/AFP/GETTY IMAGES

MATTER OF FACT

The name for the now 25-year-old encryption system Pretty Good Privacy (PGP) was inspired by Ralph's Pretty Good Grocery of Garrison Keillor's fictional Lake Wobegon.

last July that he wants to outlaw encrypted messaging systems that don't offer government authorities the means to decrypt content. And in November, U.K. home secretary Theresa May introduced a surveillance bill that would, among other things, outlaw end-to-end encryption. The debate is bound to boil over in the next few months as U.K. lawmakers work to replace the country's Data Retention and Investigatory Powers Act 2014, which is set to expire at the end of 2016.

So are Google and Yahoo headed on a collision course with the U.K. government over their end-to-end e-mail encryption? Probably not, according to Matthew Green, a cryptography expert at Johns Hopkins University, in Baltimore. "I don't think they are putting the resources behind it that it needs," says Green. He estimates that Google has one or two developers working on end-to-end e-mail encryption, too few to meet the challenge of creating a system that's truly versatile. Yahoo, too, hasn't dedicated adequate resources to the project to make their efforts successful, argues Green. "I think eventually they'll have egg on their face."

Christopher Soghoian, principal technologist of the American Civil Liberties Union, is similarly skeptical, characterizing these projects at Google and Yahoo as post-Snowden "feel-good" exercises. Soghoian notes that strong e-mail encryption goes against these companies' self-interest: "Google wants to be your brain," doing things like adding flight times to your calendar when you receive an e-mail confirmation after buying a plane ticket. "That kind of personal digital assistant is possible only if they see everything you're doing."

While he, too, recognizes the PR value Google and Yahoo gain from these projects, Joseph Bonneau, a technology fellow at the Electronic Frontier Foundation, in San Francisco, thinks that these tech giants' interest in developing end-to-end e-mail encryption is more genuine. "It's definitely a problem that Google and Yahoo would like to solve," he says. It's just that the challenges that come along with encrypting e-mail are enormous. They include figuring out how to manage people's cryptographic keys in a way that is secure and yet doesn't make users prone to losing access to their e-mail archives, how to filter spam when only the end user can read the messages, and how to enable users to search through their past messages. "The experience of Gmail would be a lot different if you couldn't search," notes Bonneau.

Both Google and Yahoo declined interview requests, so it's hard to gauge whether these companies really are determined to provide their users with encrypted e-mail this year. Even if they end up putting serious muscle behind the effort, it might still stall. It's a better bet that the main battlefield in this year's cryptowars won't be e-mail so much as instant messaging services like iMessage and WhatsApp, where users have fewer expectations for spam filtering and searching. What makes end-to-end encryption in these messaging services so attractive and popular, Bonneau says, is, ironically, that "nobody knows it's there."

—DAVID SCHNEIDER

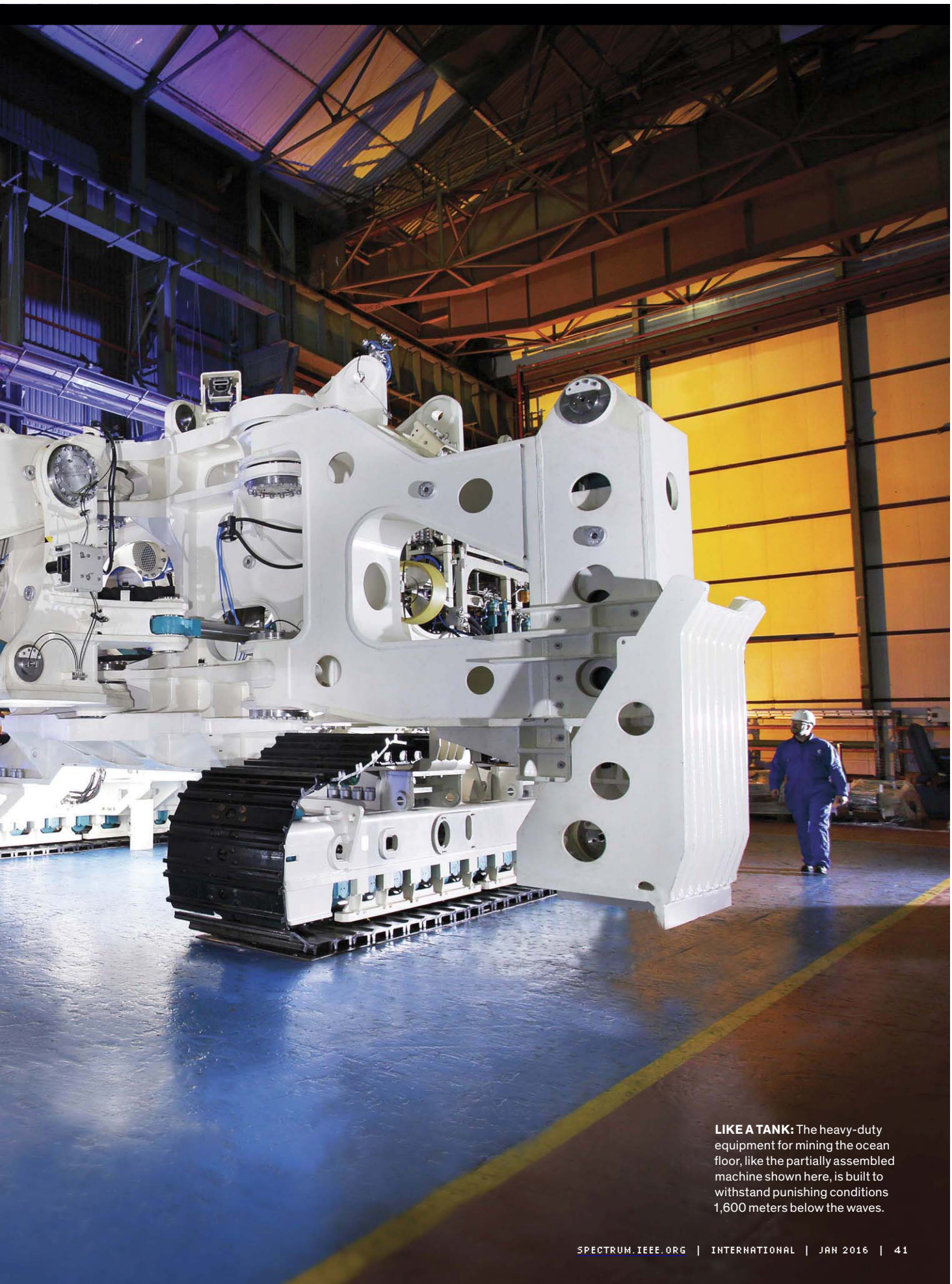
TRUTH TO POWER: Alex Stamos, then Yahoo's information-security chief, testified before the U.S. Senate's Homeland Security Committee in 2014. Stamos has since left Yahoo for Facebook, where he is the chief security officer.

WIN MCNAMEE/GETTY IMAGES

Robot Miners of the Briny Deep

Nautilus Minerals will test machines that will dig for gold in deep-sea vents

NAUTILUS MINERALS



LIKE A TANK: The heavy-duty equipment for mining the ocean floor, like the partially assembled machine shown here, is built to withstand punishing conditions 1,600 meters below the waves.

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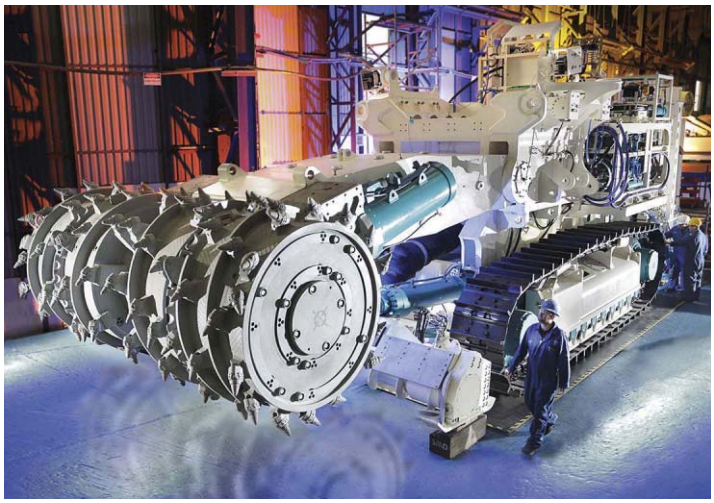
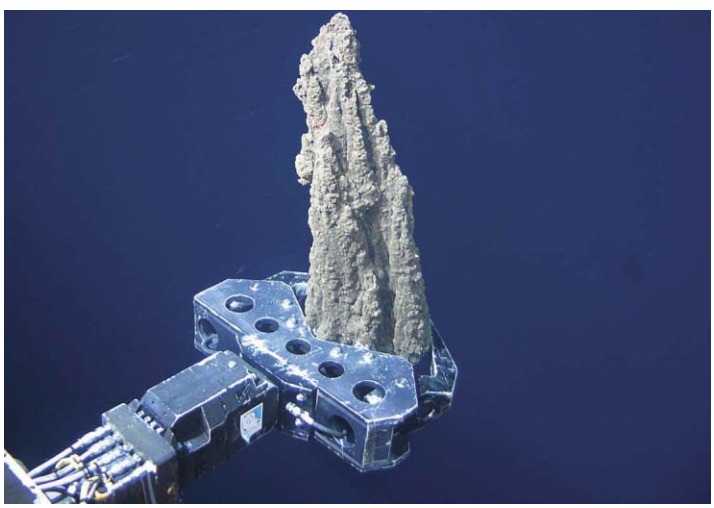




I, ROBOT MINER: Three different types of remotely operated machines will be used: a "bulk cutter" [top], a "collecting machine" [center], and an "auxiliary cutter" [previous two pages]. Clenched in a manipulator arm is a sample of the kind of metal-rich rock these robots will retrieve from the ocean floor [bottom].

FOR DECADES, FUTURISTS have predicted that commercial miners would one day tap the unimaginable mineral wealth of the world's ocean floor. Soon, that subsea gold rush could finally begin: The world's first deep-sea mining robots are poised to rip into rich deposits of copper, gold, and silver 1,600 meters down at the bottom of the Bismarck Sea, near Papua New Guinea. The massive machines, which are to be tested later this year, are part of a high-stakes gamble for the Toronto-based mining company Nautilus Minerals.

Nautilus's machines have been ready to go since 2012, when a dispute between the firm and the Papua New Guinean government stalled the project. What broke the impasse was the company's offer, in 2014, to provide Papua New Guinea with certain intellectual property from the mining project.

The deal enabled Nautilus to get financing to build a €127 million ship, the first of its kind, which will deploy the subsea mining robots and process the ore they recover. This 227-meter-long production vessel is now being built in a Chinese shipyard and is scheduled to depart for Papua New Guinea in early 2018.

The mining robots were built for Nautilus by Soil Machine Dynamics, based in the United Kingdom, which supplies construction equipment for laying undersea cables, servicing offshore oil platforms, and other heavy-duty deep-sea jobs. The main robots are a pair of tractor-trailer-size excavators. One uses 4-meter-wide counterrotating heads studded with tungsten carbide picks to chew through the metal-rich chimneys that form around superhot water spewing from sulfurous vents in the seafloor. Its partner adds brute strength, using a studded drum that is 2.5 meters in diameter and 4 meters wide to pulverize rock walls.

Dredge pumps built into these machines will push the smashed ore back to a central pile on the seafloor, where a third Nautilus robot will feed a slurry of crushed rock and water up a pipe dangling from the production vessel. There the water will be wrung out from the ore, which will be loaded on another ship and carried to China for processing.

As 2015 drew to a close, Nautilus was still negotiating for access to a shallow-water site for an initial subsea test of these machines, which it hoped to begin in mid-2016. The plan is to do some rock cutting, though in an interview Nautilus's CEO,

NAUTILUS MINERALS (3)

MATTER OF FACT

A ship called the *Hughes Glomar Explorer* was constructed in the 1970s, ostensibly for deep-sea mining, although it was in fact used to recover a sunken Soviet submarine.

Michael Johnston, says it is "difficult getting materials that are a good proxy for the materials we'll be mining." If time allows, the machines will also get a deep-sea trial before they are integrated with the production vessel, Johnston adds. Barring that, they will have to prove their stuff at Nautilus's first mining site, called Solwara 1, which is located some 30 kilometers from shore in Papua New Guinea's New Ireland province.

Assuming all goes well, the robotic diggers will spend 30 months scouring the Solwara 1 site, bringing up 2.5 million metric tons of ore containing metals worth more than US $1.5 billion at today's prices. Next, the robots will likely set to work on one of Nautilus's 18 other prospects in the Bismarck Sea or one of its 19 discoveries off the shores of the Polynesian archipelago of Tonga.

Competitors are staking out deep-sea mining sites of their own, with much of the development activity focused on rich deposits of polymetallic nodules in a vast region southeast of Hawaii known as the Clarion-Clipperton Fracture Zone. The potato-size nodules, found in waters more than 4 km deep, contain manganese along with nickel, cobalt, and other metals.

But some marine biologists warn that deep-sea mining interests are outpacing the readiness of scientists and governments to assess and manage the environmental impact. Verena Tunnicliffe, a specialist in deep-sea vent ecosystems at the University of Victoria, in British Columbia, Canada, says robominers will strip away deep-sea ecosystems that are as unique as they are poorly understood.

Johnston points out that Nautilus is taking pains to study these ecosystems and will protect them to the extent possible. A refuge zone within the leased area, for example, will provide a source of local fauna for recolonization of the company's deep-sea strip mine.

Tunnicliffe worries that this vision for recolonization could prove wildly optimistic: "The habitat is going to be pulverized, and the energy flow of the system will be completely altered. I do not believe recolonization of these types of populations is going to happen."

Other marine biologists are more sanguine, however. With luck, the mining will prove no more devastating to these vent communities over the long term than the frequent earthquakes and outpourings of lava that these amazing deep-sea creatures are somehow able to survive. —PETER FAIRLEY

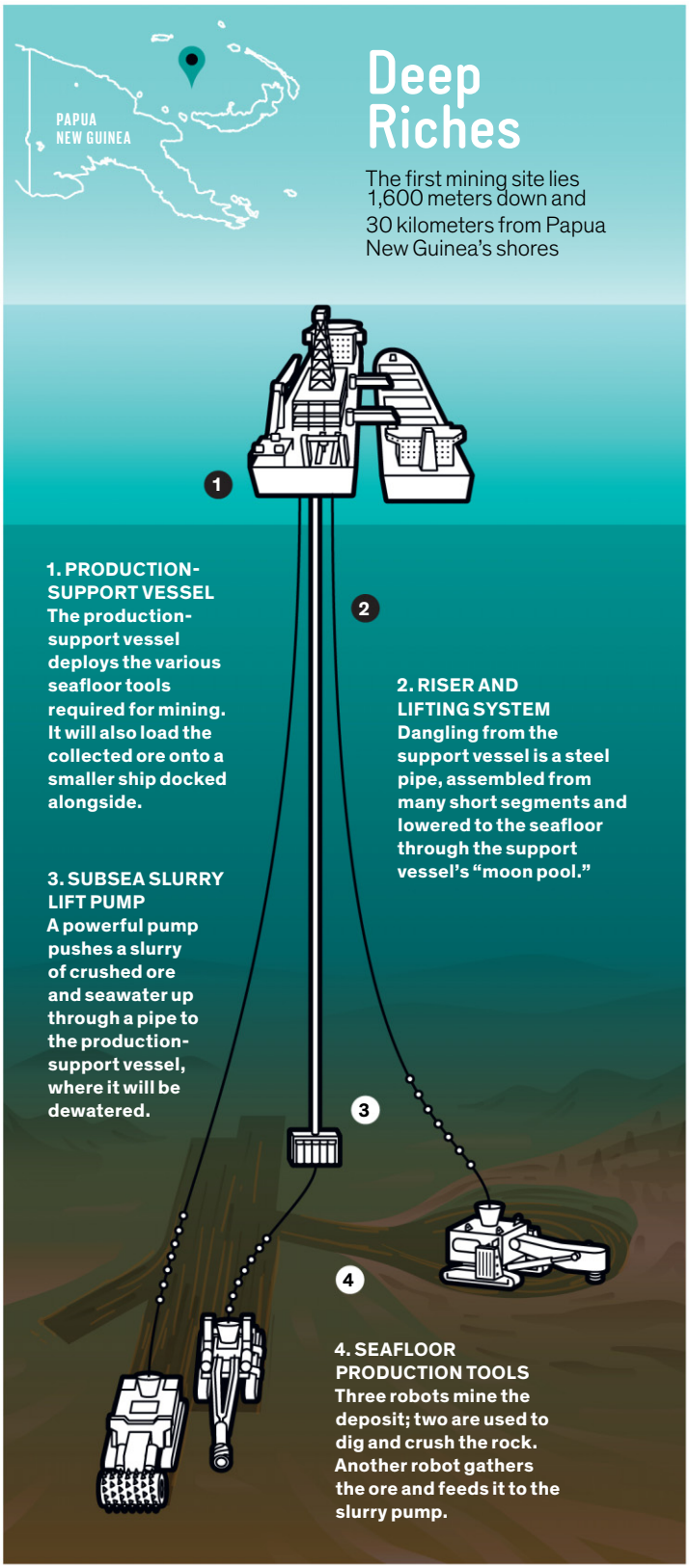


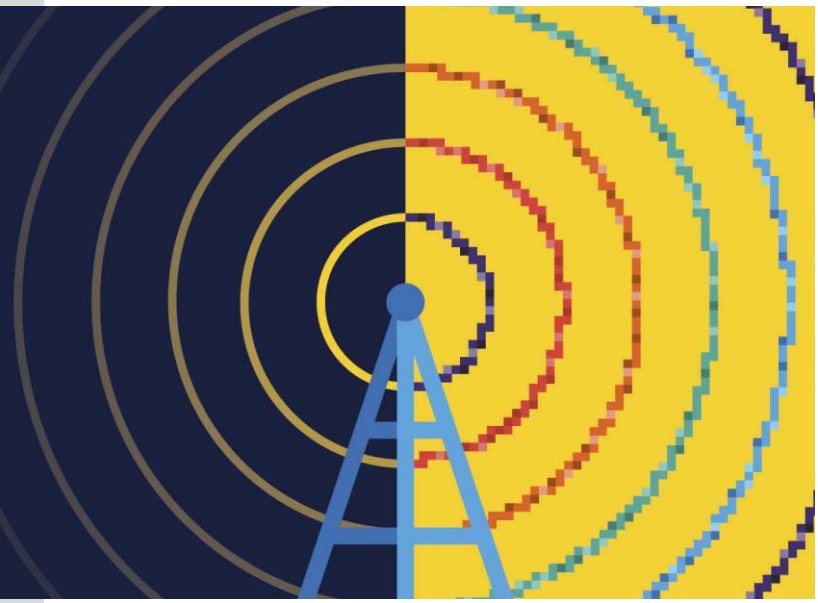
ILLUSTRATION BY James Provost

Northern Lights Out for Analog Radio

Norway is the first country to make the switch to digital

MUSIC RECORDINGS, VIDEO, TELEVISION, and motion pictures—all have started or completed the transition from analog to digital. Oddly, though, broadcast radio remains largely analog around the world, despite the availability of digital services for more than a decade. But a major milestone for digital radio is coming next year, in Norway of all places.

The world's big broadcasters will be tuning in to see the preparations this year as Norway moves its national FM broadcasters from analog transmissions to a digital format. The switchover will be to the Digital Audio Broadcasting (DAB) standard, a European-originated system also making inroads in Asia and Australia. (In the United States, the HD Radio standard has had a lukewarm reception with consumers since it was introduced in 2003.) Starting in stages from January of 2017 and rolling through the long length of the country, Norway's three national broadcasters, several regional commercial stations, and many urban transmitters will fall silent on FM bands while filling the air with digital packets broadcast at higher frequencies.



It's been a deliberative process since the idea gained momentum in the Norwegian Parliament in 2011. To trigger the shift, NRK, Norway's government-owned broadcaster, needed its digital coverage area to encompass 99.5 percent of the country's population, which it did. At least 50 percent of Norway's broadcast audience now listens daily to digital radio, which offers more program choices than FM.

But shifting to digital isn't easy for everyone, especially for those who listen to the radio in their automobiles. Many cars, even some brand new ones, do not have DAB-compatible receivers. As a result, all counties in Norway and at least half the nation's municipalities have places where people can take their cars for modification at "an economically and technically satisfactory level," says Øyvind Christensen, deputy director general at the Ministry of Culture. He adds that adapters are available for under €100 (around US $110).

But even if the technical and economic hurdles prove easy to overcome, there is some fear of unintended consequences. Svein Larsen heads Norway's community radio association, whose member stations are for the most part locally owned and operated. He explains that these station owners worry that an all-digital platform might entice bigger networks from outside the country to enter the market and squeeze out the country's many community stations. So even with ostensibly more choices in programming, the offerings might end up being less diverse.

Norway Counts Down

JUNE 1995
Trials of Digital Audio Broadcast radio begin in Norway, lasting through 1999.

MAY 2007
Norwegian minister of culture issues a report on broadcasting in the digital era.

FEBRUARY 2011
Norway's government proposes a timetable for switching off FM.

APRIL 2015
Norwegian officials confirm the date of transition.

JANUARY 2017
Most Norwegian broadcasters to cease transmitting analog signals.

MATTER OF FACT

Right now, there are 22 national Digital Audio Broadcasting channels in Norway, offering considerably more choices than the five national FM-radio channels.

On the plus side, digital radio will save money for the national broadcasters and create more bandwidth for additional programming. "It would be at least as expensive to renew the old FM network as it would be to invest in a new digital service," Christensen says.

Norway's DAB network needs 950 transmitters to reach its required coverage area and for the most part will use existing antenna masts. With FM, analog signals are broadcast at somewhere between 87.5 and 108 megahertz (also known as VHF Band II). With DAB, the signal leaves the transmitter in digital data packets on VHF Band III, from 174 to 240 MHz. The big stations are simulcasting on both bands already. Shuttering FM analog will save them 200 million Norwegian kroner (around $23 million) a year.

But what happens when drivers enter Norway from, say, Finland? Will their radios suddenly fall silent? Not exactly. They'll still be able to tune in local community stations, which will keep their FM licenses and will be free to continue broadcasting in analog. National broadcasters and some two dozen commercial stations in the cities of Oslo, Bergen, Trondheim, and Stavanger, however, will be required to make the shift.

Other European broadcasters will be watching Norway closely to see how all this plays out. Denmark and Switzerland are quite close to being able to move away from FM, says Peter Senger, former research and development head for the German broadcaster Deutsche Welle and longtime champion of digital broadcasting. In other countries—notably the United Kingdom and the United States—the shift toward digital radio is proceeding at a glacial pace.

Six years ago the administration of U.K. prime minister Gordon Brown produced a report, *Digital Britain*, calling for a complete shift to digital radio in the country by the end of 2015. It hasn't quite worked out that way. "There's been a conscious decision in the U.K. not to announce anything like switchover, because we're not there yet in terms of listening figures," says Stephen Lax, a lecturer in communications technology at the University of Leeds. "Finland's failed with digital radio twice already," says Marko Ala Fossi of the University of Tampere, in Finland. "Both were supposed to be the future of digital radio."

It seems even in 21st-century Europe, old-fashioned FM radio, like an old soldier, may never die—it will just fade away. —MICHAEL DUMIAK

China's Comac to Challenge Boeing and Airbus

The company's C919 airliner is slated to begin flight tests soon

THE C919, CHINA'S ANSWER to the Airbus A320 and Boeing 737, is slated to have its first test flight later this year. Built by the Commercial Aircraft Corporation of China (Comac), the twin-engine airliner had its celebratory rollout last November in Shanghai. But even if this year's flight-testing goes well, don't expect to fly on a C919 right away. Indeed, if you live in Europe or the United States, don't expect to even see one at your local airport.

Although the C919 is a homegrown Chinese creation, the aircraft isn't completely Chinese. Comac uses many of the same U.S. and European components as Boeing and Airbus do in their 737 and A320 airliners, including Honeywell's flight-control system, Parker Aerospace's hydraulic equipment, and Liebherr's landing gear. But like Boeing and Airbus, Comac has the responsibility of ensuring that all those systems—and many more—work together smoothly. And that's not an easy task: Problems with systems integration contributed to the lengthy delays with China's ARJ21, a regional jet that first went into development in 2002 and will go into widespread commercial service only this year—eight years later than originally planned.

MATTER OF FACT

Pricing has not been announced, but the C919 is expected to cost about US $50 million, much less than Boeing's 737-800 ($96 million) and the Airbus A320 ($97 million).

THE BIG DEBUT: Comac celebrated the first C919 to roll out of the factory in early November of 2015 [top]. A mock-up of the new plane's passenger cabin [bottom] was used to develop the ventilation system.

Wu Guanghui, vice president at Comac and chief designer of the C919, says his company does recognize that systems integration is a key challenge, which is why Comac built a fully functioning "iron bird" in 2014. Housed at the Shanghai Aircraft Design and Research Institute, this prototype is used to test various subsystems and moving parts, including the landing gear, rudder, horizontal stabilizers, elevators, slats, flaps, ailerons, and spoilers.

Like a proud parent, Wu extols the plane's virtues: "The aircraft uses the very best of domestic and foreign resources, and was designed and made in accordance with international standards," he declares. Maybe so, but there can still be surprises. Sometimes it becomes apparent only after rollout that an aircraft is overweight, as Boeing learned with its 787. And the initial batch of ARJ21 aircraft that Comac built were also heavier than anticipated, forcing the company to go back to its suppliers seeking ways to shave off kilograms.

Weight is critically important because the heavier an aircraft is, the less fuel efficient it is. And airlines, of course, want the most fuel-efficient aircraft they can get. So if the C919 is too heavy, it will be hard to sell.

Comac is a state-owned company, and nearly all of the orders for C919s are from other Chinese state-owned firms. The lone exception at this point is U.S.-based GE Capital Aviation Services (GECAS). And it may be no coincidence that GECAS's sister company, GE Aviation, owns 50 percent of CFM International—the sole engine supplier to the C919 program with its CFM LEAP-1C engine.

In 2008, when the C919 program was launched, Comac hoped that the LEAP engine would give the C919 greater fuel efficiency than the A320 and 737NG, which are powered by the CFM56 engine, an older and less fuel-efficient design. But since then, Airbus and Boeing have come out with the A320neo and 737 MAX, which are both powered by the LEAP engine, thus negating the C919's competitive advantage.

So far, Chinese aircraft makers have been unable to get even a single commercial plane certified by either the United States' Federal Aviation Administration or the European Aviation Safety Agency (EASA). And that losing streak is unlikely to end with the C919, because the plane was designed and built with no involvement from either the FAA or EASA. To gain such certification, a company normally needs to include the regulators from the get-go. And without FAA or EASA certification, it will be nearly impossible for Comac to succeed in selling its aircraft abroad.

Hugh Newman, technical director at the Bank of China's aircraft leasing company, BOC Aviation, points out another reason why you're not going to see many C919s outside of China anytime soon: "They don't have the international customer-support network. It is something that has taken Airbus and Boeing decades to develop, and it's not something that can be replicated in a few years."

Will Horton, senior analyst at the Australian-based Centre for Aviation, says that, apart from its domestic market, Comac will be limited to selling the C919 to developing countries that are political allies of China. "We've seen other indigenous Chinese aircraft—such as the Xian Aircraft MA60 turboprop—acquired by foreign operators as part of broader economic and political packages," he notes.

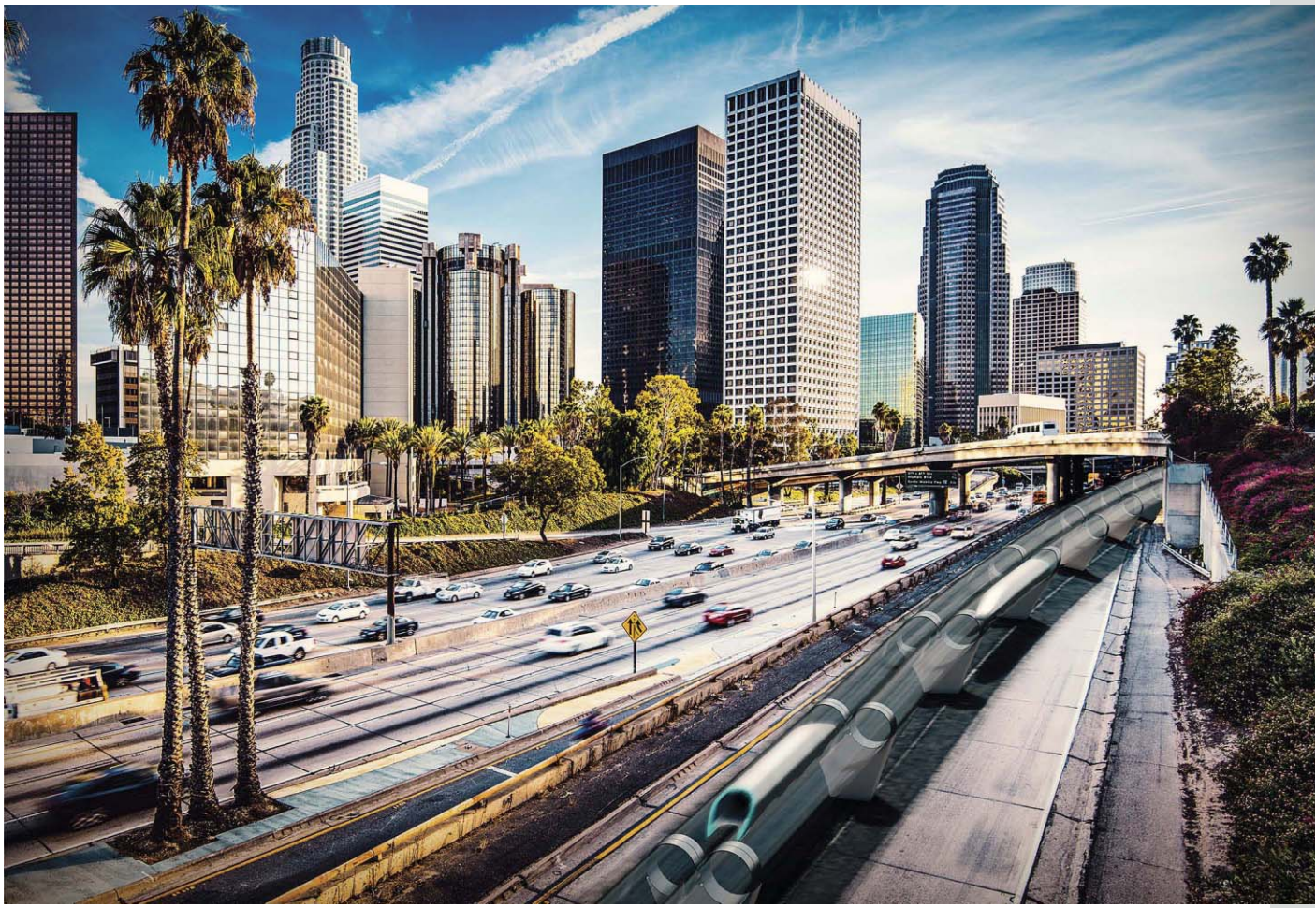
So if you're an air-travel aficionado who just has to try every kind of airliner there is, you'll likely need to buy a ticket to China, on something other than a C919, to find a seat on this new cruiser in the sky.

—LEITHEN FRANCIS

CHINAFOTOPRESS/GETTY IMAGES (2)

MATTER OF FACT

In the 1970s, Swissmetro proposed a system of evacuated tubes that would conduct trains at 500 kilometers per hour. In 2009, the project folded for lack of funding.



Hyperloop: No Pressure

The vacuum train project will get its first test track this year

IN 2013, ELON MUSK HAD AN IDEA. He would propel passengers in a pod through an evacuated tube at nearly the speed of sound, hurtling them from Los Angeles to San Francisco in 30 minutes. It's a lot quicker than the 2 hours and 40 minutes of the rival technology, a proposed high-speed train.

He called this scheme the Hyperloop and said it would cost US $6 billion to build versus $60 billion for the train. And because the Hyperloop's friction-free movement would save energy, operating costs would be lower, too.

THE STRAIGHT ROAD: Only when dawdling in the city can Hyperloop capsules handle more than a gentle curve.

Then Musk pulled out, citing prior commitments to his existing startups, Tesla Motors and SpaceX. But to encourage others to implement his proposal, he had SpaceX organize an open design competition, whose first round—a design contest—was scheduled to take place this month, as this issue was going to press. It attracted more than 1,200 registered teams, mostly of engineering students. But the contest was no mere science fair. Now there are two startups—Hyperloop Transportation Technologies (HTT), founded in 2013, and Hyperloop Technologies, in 2015.

Yes, the idea is crazy. But not as crazy as you think, and *not at all* for the reasons you think it is.

HTT

SKELETON OF WOOD: This model of a Hyperloop capsule was built by students at Suprastudio, part of the architecture school of the University of California, Los Angeles.

YOU'VE GOT TO HAND IT TO ELON. Actual folding money has been raised, and this year actual ground is to be broken, on HTT's 5-mile (8-kilometer) test track in California. All this without any key breakthrough to brighten the outlook of what is a very old idea. In 1906, future rocketeer Robert H. Goddard wrote a sci-fi story on the idea for a college class (incorporating ideas that he later patented; see illustration, "A Rocket Man's Dreams"). The only new thing is the enthusiasm of Musk, a man who has already made big promises and delivered on them.

Musk managed to position the scheme as a modest proposal—this is part of his genius—by sketching out specifications far less thrilling than those of Goddard and his successors. Robert Salter, for example, was a Rand Corp. analyst who imagined firing pods from New York to Los Angeles in 21 minutes (as this magazine described in 1984).

Salter's decidedly immodest proposal would put you in a capsule in New York or Japan, levitate you above a magnetic track to sidestep rolling friction, accelerate you along a linear induction motor—essentially an electric motor rolled out flat—then let you coast losslessly through a nearly perfect vacuum at Mach Plenty. The top speed would be cleverly limited so as to avoid a sense of weightlessness caused by following the curvature of the Earth at high speed. Finally, the capsule would decelerate along another linear motor functioning as a generator, to scavenge energy for reuse. Hello, other side of the world!

By contrast, Musk's capsule would travel at subsonic speeds in a much softer vacuum, a concession that allows his pod to be borne on a cushion of air (and still be propelled electromagnetically). It's a strategy many student teams in the design competition appear to be following, although HTT still prefers magnets. The air cushion would be fed by the output of a battery-powered compressor at the front of the pod, another reason why the system could work only at subsonic speed.

One thing student teams and other enthusiasts are supposed to do is find and correct errors in Musk's sketchy proposal. It's crowdsourcing, and it's working. For instance, after a temporary U.S. government shutdown forced some NASA researchers to find something else to do with their time, they tackled the Hyperloop's turbine idea and found it needed tweaking.

HTT

MATTER OF FACT

In 1985, scientists at MIT used electromagnetic propulsion to fire a Ping-Pong ball through an evacuated tube.

"Compressors won't go beyond a certain speed" unless you expand the cross-sectional area of the turbine's intake in comparison with its payload, says Jeffrey Chin, an aerospace engineer at NASA Glenn Research Center, in Cleveland. "Since you can't shrink people, you must expand the tube." Indeed, the most recent specs for the Hyperloop require a tube more than twice as wide as the pod.

EVEN AT A MERE 1,200-PLUS kilometers per hour (760 miles per hour) the Hyperloop would still be far faster than existing airliners—and faster yet in *effective* speed because, like trains, it would connect cities at their centers. But also like trains, the Hyperloop couldn't go just anywhere, so its technological sweet spot would be middle-range trips—such as the 560-km stretch from L.A. to San Francisco.

Musk, who holds a degree in physics from the University of Pennsylvania, got the science essentially right. You can indeed maintain a nearly friction-free surface, either with air cushions—as the hovercraft people will testify—or with magnets, as the maglev people will affirm. Civil engineers can lay a very straight track. Linear accelerators work.

And you need pull only a partial vacuum. HTT is talking of a tube pressure below 100 pascals, which is a thousandth of an atmosphere. It's not onerous at all, insists Carl Brockmeyer, head of business development at Oerlikon Leybold Vacuum, an outfit based in Cologne, Germany, that is collaborating with HTT.

"I'm tempted to say it's easy, but better to just say it's very achievable—this will not be the big technology difficulty," says Brockmeyer. "We are most likely suggesting a displacement pump," he adds. "I'm not entitled to tell you how much equipment we're going to use, but it depends not only on what's necessary to keep vacuum—we also need a redundant system," he goes on. "Maybe we'll install an extra pump in case we need to exchange pumps or to not have to run them all at full speed."

To answer these and other questions, HTT plans to begin constructing its 5-mile test track later this year in Quay Valley, Calif., halfway between L.A. and San Francisco. By the way, that's also the site of a proposed solar-powered city—which is convenient, given that Musk is now also making battery storage for solar homes and because his specs call for powering the Hyperloop with tube-mounted solar panels.

Other questions to be answered at the test facility include these: How would you—pardon the expression—evacuate passengers in an emergency? What happens to followers if a pod up ahead has to stop short? How do you avoid pileups during the deceleration phase? Restart the system once you've repressurized all or part of it? And how well will civilians bear the stress, with high-def screens substituting for portholes to ward off claustrophobia and with *g*-forces reminiscent of roller coasters?

About that last one, at least, some observers are squeamish. "It's not transportation; it's a barf ride," comments Alon Levy, a Stockholm-based mathematician who blogs on transportation.

HTT is facing this and other aerodynamic problems, says Craig Hodgetts, the chief architect of the project and a professor at the University of California, Los Angeles. Its evolving design is now rather different from the original Musk vision, which he says is one reason why HTT won't participate in the SpaceX competition.

> "It's not transportation; it's a barf ride," comments Alon Levy, a Stockholm-based mathematician who blogs on transportation

"The artist's sketches that accompanied Musk's proposal consider the capsule with a kind of sloping nose akin to that on high-speed-rail trains," Hodgetts says. "That's an appropriate configuration if you're not in a tube, but in a tube the ideal shape is symmetrical all the way around. So we made quite a difference in terms of locating the capsule in the tube."

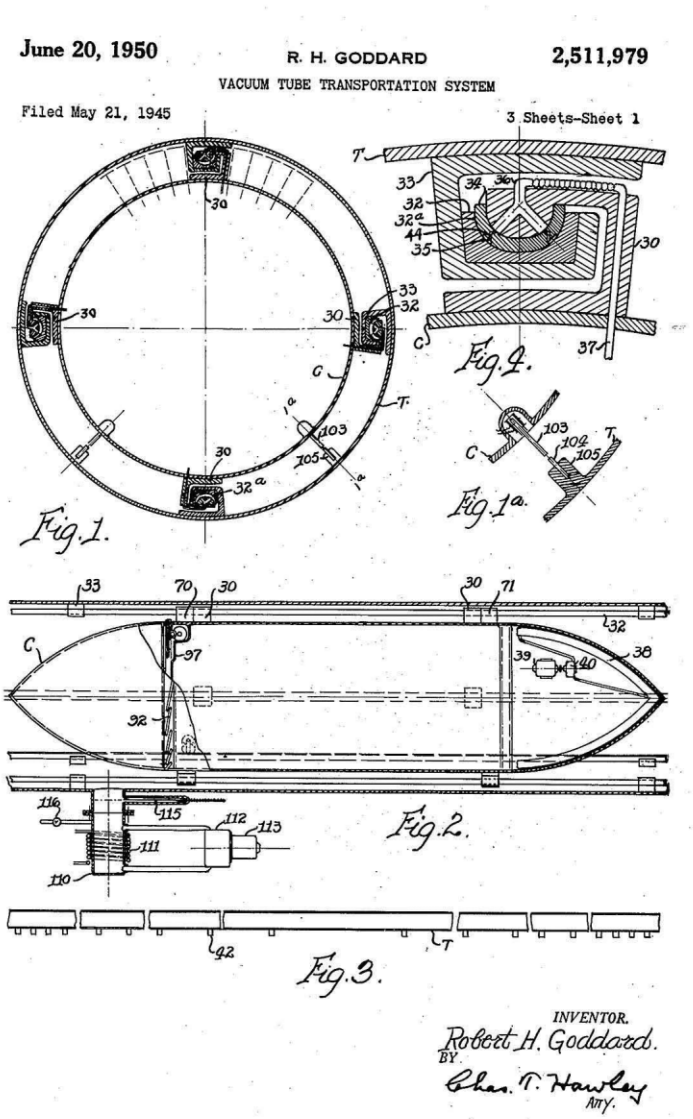
Because HTT will suspend its pod magnetically rather than pneumatically, it will need a smaller frontal compressor turbine than originally envisioned, he says. That means the pod can get along with lighter batteries and cooling systems. That weight reduction should minimize buffeting (and barfing). But work is still going on to figure out how passengers will cope with acceleration.

"My sense is there will be fine-tuning at the Quay Valley installation," Hodgetts concludes. "Some of our research indicates that at full speed it'll pull 1.5 *g*'s in a 15-mile turning radius—quite a lot. That's a big determinant in laying out a route. And it doesn't look like it'll be practical to slow capsules down to any degree in order to maneuver, so there has to be a very sophisticated analysis of speed, route, and sensation."

LET'S SAY THE ERGONOMIC ISSUES can be solved—and that, with enough backup systems, the safety challenges can, too. Now the really big problem is, of course, money.

Hodgetts asserts that building the tube itself is actually not a hard problem: "It's several tiers down from building a skyscraper 1,000 feet high, where you have unpredictable wind forces, possible seismic forces, shrinking concrete."

Other experts are a tad less sanguine. "This is a huge project that no one has ever done, and he [Hodgetts] is promis-


June 20, 1950 R. H. GODDARD 2,511,979
VACUUM TUBE TRANSPORTATION SYSTEM
Filed May 21, 1945 3 Sheets-Sheet 1
Fig. 1.
Fig. 1a.
Fig. 2.
Fig. 3.
Fig. 4.
INVENTOR. Robert H. Goddard. BY Chas. T. Hawley ATTY.

A ROCKET MAN'S DREAMS: Robert H. Goddard, father of modern rocketry, first envisioned a Hyperloop-like system in 1906.

ing this thing at really a ridiculous cost, not knowing if it will work," says Leon Vanstone, a postdoc who studies high-speed aerodynamics at the University of Texas at Austin.

"If you fire it down at high speed, very small deviations in the tube can cause buffeting," Vanstone adds. "Even if you can get it quite straight in the first place, the ground moves, especially in California. It could be loud; it could be rattly."

These problems will probably not dominate the open competition this month. It involves design, not a trial run, so the registered teams have so far been able to make do with university funding, freebie modeling software, and the odd gift from corporations. Students who spoke to *IEEE Spectrum* said their research funding would likely be under $100,000—in the short term. When actual trials must be run, more funding will be needed to compete.

"We'll build and design a test model to compete in this winter's competition," says David Coven, a mechanical engineering student who's leading the University of Washington team. "It won't be full size—more like 3 by 4 by 14 feet, like a Formula One. We'll also be building a test tube 1 mile long."

Bigger fish may enter the competition in its later phases. Chin, of NASA, hinted that he and his colleagues might want to give it a try. He is already thinking of how the problem changes as you move from the design to the testing phase. "The devil is in the details, when it comes to moving to a bigger system," he says.

LEGAL AND POLITICAL OBSTACLES may eclipse even the economic ones. New York City's subway system is supposed to open the first stretch of its Second Avenue Line at the end of this year. The relevant numbers: 3.2 km (2 miles), $4.5 billion, and nine years. That's how long it will have taken to build, if you count from the day workers broke ground (and 97 years if you start with the day the line was first proposed).

True, Manhattan's depths are riddled with pipes, cables, maybe Morlocks. But the main impediments here were not metal and dirt but rather even grubbier stuff: politics and lawyers. And the same could be true for the Hyperloop. Musk has argued that right of way could be had for a song by building alongside existing power lines. Good luck with that.

But when the day comes that public officials are asked to approve a Hyperloop and pony up the funds, the merry pranksters of the Hyperloop will face serious opponents armed with spreadsheets of their own. Unless they go to a country where the political leadership can be relied on to make things happen.

Maybe that's why Dirk Ahlborn, the CEO and founder of HTT, spent the tail end of the summer in Asia. When *Spectrum* caught up with him, in late September, he wouldn't reveal exactly where he'd been, but he did say where he was going.

"I can say for sure the first full-length track will be in Asia, the Middle East, India, or Africa," Ahlborn said. "They have bigger issues and no existing infrastructure, so a real need to build. A system like ours is way more interesting for them than going with high-speed rail." —PHILIP E. ROSS

U.S. PATENT AND TRADEMARK OFFICE

MATTER OF FACT

Mycoplasma laboratorium: **The name given to the first "synthetic organism," a bacterium whose 1-million-base genome was assembled from scratch.**

DNA Manufacturing Enters the Age of Mass Production

Synthetic-biology startups adopt technologies from the computer industry

EMILY LEPROUST, CEO AND COFOUNDER of the buzzy biotech startup Twist Bioscience, is an industrialist on the nanoscale. "I remind everyone at Twist, we are a manufacturing company," she says. "We manufacture DNA."

Twist is part of the young industry of synthetic biology, in which living organisms are the product and a biology lab is the factory floor. By manufacturing strands of DNA—assembling the genetic code of life from its basic components—scientists are creating organisms the likes of which the world has never seen. And these new life forms can be decidedly useful: Biologists have produced yeast cells that excrete pharmaceuticals and algae that brew jet fuel.

This burgeoning business sector has been hampered by the labor-intensive nature of DNA assembly, a painstaking process requiring trained personnel. Now, nimble startups are competing to fashion automated DNA assembly lines that would make Henry Ford proud, using techniques copied from the fabs that make computer chips. As their innovations bring down the cost of constructing DNA strands, these entrepreneurs are aiming for a low price point, which they say will cause a market boom. Twist Bioscience, which will begin commercial operations at its San Francisco headquarters this year, is a leading contender in that race to the bottom.

Genetic material is composed of molecules called nucleobases; the four types of bases in DNA are identified by the letters A, C, G, and T. The order of these letters serves as a code that instructs an organism how to build its cells and carry on the functions of life. In human beings, this code is about 3.2 billion letters long, while the yeast used in baking and beer brewing has a code of about 12 million letters. If you tweak the order of the letters, you tweak the organism's instructions. Synthetic biologists have written new snippets of code and inserted them into yeast DNA, causing the microbe to churn out, for example, the omega-3 fatty acids found in fish oil supplements or the aromatic oils normally produced by roses.

Constructing a strand of DNA isn't complicated; in fact it's a routine procedure performed in labs all over the world. But that procedure is typically carried out by hand, says Twist's Leproust: "Microbiology is manual labor. You have a Ph.D. student moving liquid from one test tube to the next all day long." So she and her cofounders invented a machine that automates the construction process.

The heart of the machine is a silicon plate pocked with 10,000 tiny wells, which are etched using the same photolithography techniques perfected by computer chip manufacturers. A different strand of DNA can be constructed in each 600-nanometer-wide well. The machine does "the exact same chemistry" as a Ph.D. student would do, Leproust says, "only in a volume that's 100 times smaller."

Twist isn't selling its machine but rather its DNA manufacturing services, which are aimed at researchers and startups seeking new genetic modifications that might prove useful. Last year the company began production runs for select customers; this year will see Twist's full commercial launch. DNA assembly is priced on a cost-per-base model, and Leproust says her

1,600 BASES
Length of gene for insulin (INS)

81,000 BASES
Length of gene for breast cancer risk (BRCA1)

MATTER OF FACT

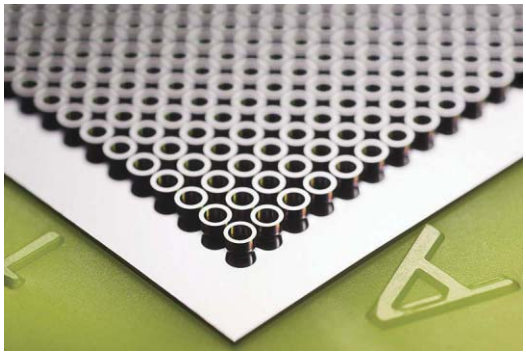
People who sawed down a virtual tree at Stanford's Virtual Human Interaction Lab later used 20 percent fewer paper napkins.

company's 10-cents-per-base starting price is already the best in the industry. But she's aiming for a 2-cent price point: "That's the point at which researchers can significantly scale experiments and will no longer be limited by the cost of DNA," she says. Today, customers typically order DNA strands of 300 to 1,800 bases in length, Leproust says.

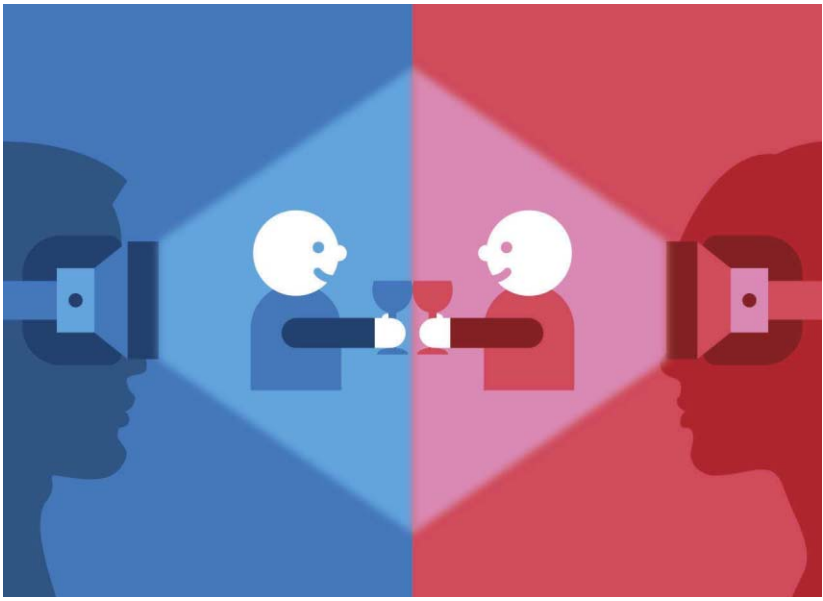
Another synthetic-biology startup in the San Francisco area, Zymergen, offers customers a broader set of services. The company not only constructs DNA snippets on the cheap, it also inserts that DNA into microbes and monitors the outcome. Chief science officer Zach Serber explains that the results can inform the next round of DNA design, letting customers iterate quickly as they look for their ideal organism. "You cast a wide net," Serber says, "and when you find a variation that improves the microbe's performance, then you double down."

Such setups have led to excited talk of a synthetic-biology industry based on "organism fabs." But the promise of mass-produced DNA doesn't impress Rob Carlson, a biotech consultant and managing director of the BioEconomy Capital venture fund. "I don't understand the business model," he says.

Carlson is skeptical that cheap DNA assembly will lead to a proliferation of startups with ideas for profitable microbes. "So you can make and test a whole bunch more DNA–but that's not the hard part," he argues. "Going from test tube to bench scale to commercial scale, that's 90 percent of cost." For a startup to build a business around a yeast that cranks out a pharmaceutical, for example, it must manage massive tanks full of microbes. Reducing the cost of the initial DNA manufacturing would only give the company pocket money, Carlson says: "Hooray, they get to buy beer, or more pizza on Friday." –ELIZA STRICKLAND



DNA FACTORY: Twist Bioscience's machine builds DNA strands inside 600-nanometer wells on a silicon plate.



Virtual Reality Goes Social

Meeting people, not playing games, will be VR's killer app

THE DOOR TO MASS-MARKET VIRTUAL REALITY is about to burst open. Engineers have solved most of the hardware challenges, driven down the price to just a few hundred dollars, done extensive testing, and gotten software tools into the hands of creative developers. Store shelves will soon be teeming with head-mounted displays and hand controllers that can paint dazzling virtual worlds. And then the first wave of VR immigrants will colonize them.

You might think the first adopters will be gamers, but you'd be wrong. The killer app for virtual reality will more likely be something to enhance ordinary social experiences–conversations with your loved ones, a business meeting, a college class–but carried out with a far richer connection than you could establish by texting or talking or Skyping.

Jeremy Bailenson, founder of Stanford's Virtual Human Interaction Lab, and his coauthors predicted in these pages in 2011 that such "social VR" was on the horizon. "Current social networking and other online sites," they wrote, "are just precursors of what we'll see when social networking encompasses immersive virtual-reality technology. When people interact with others for substantial periods of time, much as they do now on Facebook but with fully tracked and ren-

TWIST BIOSCIENCE

dered avatars, entirely new forms of social interaction will emerge." With the variety of head-mounted displays—including the Oculus Rift, Sony's PlayStation VR, and the HTC Vive—going on sale later this year, that future is now here.

VR WILL GROW 200-FOLD FROM 2014 TO 2020

Worldwide revenue for VR hardware and software is projected to increase from US $108.8 million to $21.8 billion.

AT ITS MOST BASIC, social virtual reality allows two geographically separated people, in the form of fairly realistic avatars, to communicate as if they were face-to-face. They can make eye contact and can manipulate virtual objects that they both can see. It's somewhat like telepresence, but VR denizens won't have to worry about appearing at a business meeting in pajamas. (Their avatars will, no doubt, be impeccably dressed.) And they'll be a lot less likely than the users of telepresence systems to struggle with frozen images or interrupted calls, because their VR gear needs to send instructions only about how to move the avatars, not the entire image.

Of course, this year's VR technology won't be perfect. Headsets won't be able to track exactly where your eyes are pointed; for example, the software will assume you're looking at the person you are talking to. And they aren't yet reading detailed facial expressions, in no small part because the gear blocks half the face, although ways around that obstacle are being developed; the gadgets do know when you turn your head or nod.

For the more powerful systems, you'll be tethered to your computer with cables, because the amount of data needed to transmit high-resolution video at high frame rates overwhelms today's standard wireless technology. And the perfect user interface—the VR equivalent of the mouse—has yet to be developed. Still, the input devices coming out this year will be good enough to get social VR off the ground.

As a result, lots of folks are working to make social VR happen. Linden Lab, the San Francisco company behind Second Life, a screen-based simulation with a million active users today, is getting ready to roll out a new platform. Linden's Project Sansar is a host for user-created virtual experiences and tools to build them that will work with VR headsets, standard computer monitors, and mobile devices. The Sansar world will function much like Second Life, with people leasing space for their virtual creations, which will be rendered in 3-D and at a high frame rate. The French company Beloola is building a similar virtual world designed for social networking.

High Fidelity, the latest startup from Second Life's creator, Philip Rosedale, has a different approach: Instead of building a virtual world, the company is developing open-source software tools and offering a registry, identity verification, and other services for the virtual worlds others build. Still other companies are working on software for sharing experiences virtually: for example, watching movies or TV shows, or recording snippets of your life in 360 degrees and sharing them with friends.

To be successful, these efforts will require a critical mass. To build that, companies are counting first on selling to people who have an immediate need for social VR, say, for cutting down on business travel or improving educational experiences.

"If you could put on a VR headset and walk around an Italian street where everyone is talking Italian and interact with other students and teachers in Italian, that is real immersion, and I can do that for you cheap," says Rosedale.

Attractive as such possibilities seem, it will take time for social VR to spread as widely as some other social media. "We're not going to have millions of people in VR [in 2016]," Rosedale says. "It'll be hundreds of thousands. But the things these early adopters will be able to do—to be in a room with someone they have never met before and to communicate normally—will have such high value, they will quickly pull more people into using these things." And, as anyone who has found themselves checking Facebook more than they would like to admit knows, once you get pulled into an online world, you might find it hard to leave. —TEKLA S. PERRY

COMING ATTRACTIONS: Sony's PlayStation VR headgear [top] and High Fidelity's tools for builders of virtual worlds [bottom] will both launch in 2016.

TOP: DAVID PAUL MORRIS/BLOOMBERG/GETTY IMAGES; BOTTOM: HIGH FIDELITY

MATTER OF FACT

The global robotics market will more than double in the next 10 years, growing from US $27 billion to $67 billion, says a report from the Boston Consulting Group.

The Little Robot That Could...Maybe

Jibo is as good as social robots get. But is that good enough?

MOST OF THE WORLD'S ROBOTS are about as charismatic as a coffeemaker. Not so Cynthia Breazeal's creations. There's Huggable, a robot teddy bear, and Kismet, a babbler with big eyes, red lips, and pointy ears. Nexi is baby-faced and blue-eyed, and Leonardo has been described variously as a squirrel, a furry alien, and a giant Furby.

After years of making emotionally engaging machines with her students at the MIT Media Lab's Personal Robots Group, Breazeal thinks the time has finally come for a personal robot to inhabit our homes and help us live our lives. To pursue that goal, she founded Jibo, a Boston startup that has raised US $38.6 million to produce a friendly roboassistant to families. Equipped with cameras and microphones, the robot, also called Jibo, is a little taller than a toaster and shaped like a desk fan. It can recognize faces, understand what people say, and respond in an amiable voice. Jibo's purpose is to help busy family members coordinate with one another and communicate with the outside world. In the morning, for example, the robot can remind parents and kids of important events and tasks for the day. You can tell Jibo what you need to accomplish today, and it will update your schedule or to-do list for you while you're making breakfast. Jibo will also snap photos at parties, read interactive stories to kids, and help grandparents make video calls. First deliveries are scheduled for March and April, and the latest batch of Jibos offered for sale, at a prerelease price of $750, have been sold out since last August.

> Jibo is a "game changer in the new social robot marketplace," says one analyst

"We live in a time where so much of our technology is about data, data, data," Breazeal says. "Social robotics is about saying, 'Yes, we've got all that data. Now let's focus on the experience and the human engagement.' " Indeed, although Jibo doesn't have puppy eyes or soft fur, like some of Breazeal's previous creations, it does seem to have a personality. It can stare at you with its oddly inquisitive one-eyed face, emit cute robotic giggles, and swivel its body animatedly. "It's not just what it does, it's how it does it," she says.

To be sure, the dream of a truly useful, capable, and endearing personal robot is an old one (and no, Roomba doesn't count, unless you talk to yours). For roughly 40 years, entrepreneurs have been introducing home robots. Nearly all of them disappeared quickly and without a trace. Even Sony's iconic robot dog, Aibo, which debuted to much fanfare and attracted an avid following, failed commercially.

Now, though, the necessary technology is better and cheaper than ever before. Huge subindustries that feed the smartphone and video-game makers are also supplying components to a new generation of home robots whose main purpose is to entertain and inform their owners. Besides powerful, low-power microprocessors, the parts in these new bots include 3-D sensors that help them detect people and objects, accelerometers and gyroscopes that let them navigate better, and lightweight lithium-ion batteries that give them more autonomy.

The companies behind this emerging category include both startups and established firms. Last year, the Japanese telecom giant SoftBank began

FROM LEFT: SAM OGDEN; MIT MEDIA LAB; SAM OGDEN; MIT MEDIA LAB; JIBO

Sociable Robots Evolve

Cynthia Breazeal and her students at MIT have built an incredible collection of charismatic machines.

1998: Kismet

2002: Public Anemone

2004: Leonardo

2005: Huggable

A FAMILY ADDITION: Cynthia Breazeal hopes her social robot Jibo will become a companion for people at home.

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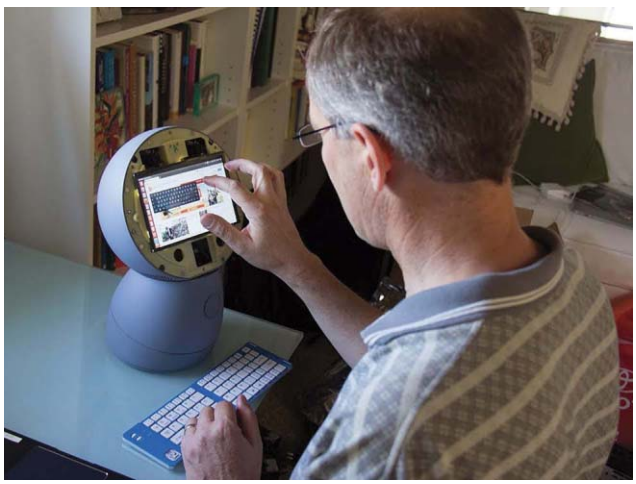
MATTER OF FACT

In 2015, robotics startups raised about US $1.2 billion in funding, nearly three times the amount raised the previous year, according to an analysis by The Robot Report.



COMING ALIVE: Andy Atkins, vice president of engineering at the startup Jibo, debugs one of the first prototypes.

selling a humanoid called Pepper, which like Jibo is mostly designed to entertain. In July, a French startup called Blue Frog Robotics plans to start shipping its first robot, Buddy, which resembles a Jibo on wheels. And several robot makers in China, including Ainemo, in Beijing, and Ubtech, in Shenzhen, are working on similar products.

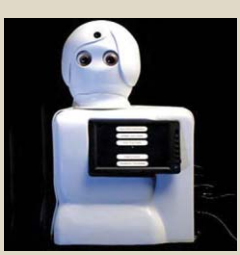
Will Breazeal's robot stand out from the crowd? Frank Tobe, an analyst and publisher of The Robot Report website, thinks it will. He calls Jibo a "game changer in the new social robot marketplace," noting that the company has assembled a talented team of experts not only in robotics but also in speech recognition, human-machine interaction, gaming, and animation. One other factor that helped sell Tobe on Jibo: He showed a promotional video of the robot to his wife, who afterward declared that "any device that can order Chinese food"–a scene shown in the video–"is a winner."

Others are less enthusiastic. Media pundits have described Jibo as an "animated lampshade" and "an alarm clock on steroids." A *Time* article says "it's unclear why you'd actually need one," adding that much of what Jibo promises to do are things your smartphone already does. And responding to another scene in the promotional video, a writer for the tech news site GeekWire said: "No way am I going to leave an Internet-connected, motorized camera next to my daughter's bed," citing privacy and safety concerns.

Breazeal takes the criticism in stride. She acknowledges that Jibo will launch with only a small set of apps (she calls them "skills") but adds that the robot is a platform open to developers to expand its capabilities. New apps will increase Jibo's usefulness over time, she asserts, and allow it to do things undreamed of now. And her team is taking privacy and safety concerns seriously, she hastens to add.

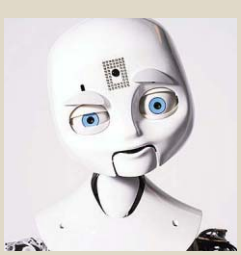
Consumer-wise, so far, so good. As of December, Jibo had done $3.7 million in preorder business on the fund-raising website Indiegogo. It's a staggering sum, especially in view of the fact that during the crowdfunding campaign, the robot was still just a crude prototype that couldn't perform any of the tasks advertised. Having already delayed the original shipping date once, Breazeal knows she and her team need to deliver on their promises. "It's heads down right now," she told *IEEE Spectrum* in an interview late last year. "Heads down."

TOP: JIBO (2); BOTTOM: MIT MEDIA LAB (4); ADAM SETAPEN



2006: Autom

2007: AUR



2008: Nexi

2009: MeBot

2011: Dragonbot

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THE FIRST PROTOTYPES OF JIBO looked like soft-drink cans with smartphones glued on them. Some models had a cartoonish antenna sticking out of the top. Breazeal and her team worked with an industrial design firm in San Francisco to create the current version, which is sleek and minimal. Packed inside is an impressive amount of electronics: high-resolution stereo cameras, six microphones, a pair of speakers, an LCD touch screen, two cooling fans, Wi-Fi and Bluetooth modules, LED lights, touch sensors, and an ARM-based embedded processor running Linux.

But perhaps the most ingenious part of the design is Jibo's body. It consists of three roughly cylindrical sections, one each for the base, torso, and head, which connect at an angle rather than horizontally. The result is that rotating these sections relative to one another causes the body to appear to bend into a variety of expressive poses. The rotation is accomplished by three DC motors with belt drives, which move smoothly and quietly.

> "Social robots are different from us and can complement us. That is what is really valuable"

Getting the movements right required substantial engineering. In early prototypes, the sections could turn in either direction by only a limited amount, which restricted the robot's range of motion and made the movements seem unnatural. To allow each section to rotate continuously, Breazeal's team rearranged the electrical and mechanical components more tightly. The team also ran all the wires through the center of the robot's body so that they won't get twisted when it spins around. According to Matt Berlin, who worked on the motion problem, Jibo now "feels much more fluid and loose, like it can just keep flowing from one pose to another without hitting any stops."

Ultimately, Jibo will succeed only if it offers a mostly flawless user experience. And this experience will in turn depend greatly on the robot's speech recognition and synthesis. That's a big challenge: Give hearing and voice to a robot and people expect it to be intelligent.

"Human conversation isn't like a Siri or Google Now request, where you form a well-structured phrase," says Tandy Trower, founder of Hoaloha Robotics, a Seattle startup developing health-care robots that will also rely on voice-based interactions. "When we speak to each other, we use a tremendous amount of context to help us understand what someone is saying." In other words, a robot like Jibo will have to take contextual details into account to be able to conduct open-ended dialogues.

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It won't be easy. Breazeal has said that the approach used by Siri and Google Now, which transmit speech to powerful cloud-based computers for processing, is poorly suited to a robot. A cloud-based speech engine would introduce delays. Worse, if Jibo loses Wi-Fi connectivity, it would become unresponsive. The alternative is to run voice recognition locally, on the robot. And that's not such a great choice either, because it would likely overwhelm its CPU. Although Breazeal won't say how her team is tackling this problem, it's possible that Jibo will combine a hybrid approach, using local voice processing for some basic functionality—when a user tells the robot to "wake up," for instance—while relying on a cloud-based engine for more complex speech processing, such as contextual evaluation of statements, for example.

Breazeal did say that her speech engineers are building natural-language models to allow Jibo to respond in an engaging manner. They've also given Jibo a unique voice, courtesy of a voice actor who recorded some 14,000 phrases. From those, a text-to-speech engine can generate millions of utterances. But she adds that the actual words the robot will say are only part of its response—it will also use body language as well as alter the tone of its voice to suggest happiness, sadness, and surprise.

Over time, Breazeal promises, Jibo will learn details about individual users, offering more personalized responses. And then, she adds, people will treat Jibo not just like another gadget but as "part of the family." That's her fondest dream, and it would be a lasting legacy to leave in robotics.

But whether it would be a good or sad legacy depends on whom you ask. "Roboticists will argue that there is no harm in people engaging in conversations with robots; the conversations may be interesting, fun, educational, or comforting. But I find no comfort here," writes Breazeal's MIT colleague psychologist Sherry Turkle in her 2011 book *Alone Together*. "A machine taken as a friend demeans what we mean by friendship. Whom we like, who likes us—these things make us who we are."

Breazeal responds that social robots are not trying to replace human friendships. They are adding to the gamut of relationships people have—with other people, with pets, and for children, even with toys. "So creating and exploring this very new kind of relationship—that's not trying to compete with any of the other existing relationships," she says. "For me, the value proposition of things like social robots is that they are not people—they are different from us. Because of that they can complement us. And that is what is really intriguing and valuable." —ERICO GUIZZO

IEEE

Introducing The New:

IEEE Transactions on Intelligent Vehicles

The IEEE Transactions on Intelligent Vehicles (T-IV) publishes peer-reviewed articles that provide innovative research concepts and application results, report significant theoretical findings and application case studies,and raises awareness of pressing research and application challenges in the areas of intelligent vehicles, and in particular in automated vehicles. The IEEE Transactions on Intelligent Vehicles will commence publication in 2016, with 4 issues annually. Prospective authors are invited to submit original contributions or survey papers for review for publication in T-IV.

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ELECTRICAL AND COMPUTER ENGINEERING, MICHIGAN STATE UNIVERSITY

Faculty Position in Accelerator Technology

Join Michigan State University's Global Impact Initiative, designed to address the grand challenges through the creation of over 100 new faculty positions in some of the most promising and exciting fields of research. We welcome applicants from diverse backgrounds. MSU offers an inclusive and collaborative work environment. To learn more visit research.msu.edu/global-impact.

The Department of Electrical and Computer Engineering (ECE) at Michigan State University invites applications for a tenure system faculty position in the broad areas pertaining to accelerator technology. Applicants must have a Ph.D. in Electrical Engineering or a related field, with expertise in, but not limited to technologies related to design of compact accelerators and components, viz, charged particle beam optics, ion sources, design of cavities and structures, electron cloud and plasma effects, and high voltage engineering.

The successful candidate will be expected to collaborate with colleagues within the ECE Department, the College of Engineering, NSCL and FRIB facilities to complement a world class accelerator program. All applications must demonstrate evidence of strong research potential, interest in both undergraduate and graduate teaching, and a serious commitment to teamwork. This position is targeted at the junior faculty level, but senior candidates with outstanding credentials may be considered.

The Electrical and Computer Engineering department has strong interdisciplinary research and educational programs on a foundation of core electrical and computer engineering disciplines and provides first-class education while engaging in research at the frontiers of knowledge. The Department has 49 faculty members, including two National Academy of Engineering members, 18 IEEE Fellows, and 13 NSF CAREER awardees. The Department has strong research programs in all major areas of electrical and computer engineering, with annual research expenditure of about $18M. Faculty in the Department are leading several federal and industry-supported centers, including the NSF Science and Technology Center BEACON, and the Fraunhofer Center for Coatings and Laser Applications. The Department has accredited B.S. degree programs in both Electrical Engineering and Computer Engineering. The current enrollment is approximately 260 full-time graduate students and 770 undergraduate students.

For additional information about the ECE Department, the College of Engineering or MSU, see: **http://www.egr.msu.edu/ece/**.

MSU enjoys a park-like campus with outlying research facilities and natural areas. The campus is adjacent to the city of East Lansing and the capital city of Lansing. The Lansing metropolitan area has a diverse population of approximately 450,000. Local communities have excellent school systems and place a high value on education. Michigan State University is pro-active in exploring opportunities for employment for dual career couples, both inside and outside the University. Information about MSU's dual career support can be found at **http://miwin.msu.edu/**. Information about WorkLife at MSU and the College of Engineering can be found at **http://www.egr.msu.edu/WE**.

Interested individuals should submit an application through: **http://jobs.msu.edu/** and refer to position **#2417**. Applicants must submit a detailed resume, a cover letter summarizing their qualifications, vision statements for teaching and research, and the names and contact information for five references. Applications will be reviewed on a continuing basis until the position is filled. For full consideration, applications should be received before **March 1st, 2016**. Nominations or questions are welcome by contacting the search committee chair through email at **ece-accel-facultysearch@egr.msu.edu**.

Michigan State University has been advancing the common good with uncommon will for more than 160 years. A member of the Association of American Universities, MSU is a research-intensive institution with 17 degree-granting colleges.

MSU is an affirmative-action, equal opportunity employer. MSU is committed to achieving excellence through a diverse workforce and inclusive culture that encourages all people to reach their full potential. The university actively encourages applications or nominations of women, persons of color, veterans, and persons with disabilities.

BAYLOR UNIVERSITY

Faculty Position

The Electrical and Computer Engineering Department of Baylor University seeks faculty applicants for a tenured/tenure-track Faculty Position at any level. Any area of expertise will be considered but applicants in computer engineering will be given special consideration. Applicants for assistant professor must demonstrate potential for sustained, funded scholarship and excellent teaching; applicants for associate or full professor must present evidence of achievement in research and teaching commensurate with the desired rank. 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/**.

Applications will be considered on a rolling basis until the **January 1, 2016** deadline. Applications must include:

1) a letter of interest that identifies the applicant's anticipated rank,

2) a complete CV,

3) a concise 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. Keith Schubert at keith_schubert@baylor.edu. Please combine all submitted material into a single pdf file.

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

Joint Institute of Engineering

Faculty Positions available in Electrical and Computer Engineering

Sun Yat-sen University and **Carnegie Mellon University** have established the **SYSU-CMU Joint Institute of Engineering (JIE)** as a conduit for innovative engineering education and research. Our mission is to nurture a passionate and collaborative global community and network of students, faculty and professionals advancing the field of engineering through education and research.

The JIE enrolled its first cohort of dual-degree M.S. and Ph.D. students in Electrical and Computer Engineering in fall 2014. All current JIE faculty members have been recruited worldwide and we continue to seek **full-time tenure-track faculty** in all areas of electrical and computer engineering. Candidates should have a doctoral degree in electrical and computer engineering, computer science or related areas, with a demonstrated record of or potential for research, teaching and leadership. The position includes an initial year at Carnegie Mellon University in Pittsburgh to establish educational and research collaborations before relocating to Guangzhou, China.

This is a worldwide search open to qualified candidates of all nationalities. We offer an internationally competitive compensation package.

Please visit jie.cmu.edu for details and to apply online.

SHUNDE INTERNATIONAL

Joint Research Institute

Research positions available in Electrical and Computer Engineering

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

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

Candidates with industrial experiences are preferred. Application review will continue until the position is filled.

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

Email applications or questions to sdjri@mail.sysu.edu.cn.

SUN YAT-SEN UNIVERSITY Carnegie Mellon University

Ryerson University

Faculty of Engineering & Architectural Science

Tenure Track Faculty Position in Electrical & Computer Engineering *and Master of Digital Media*

Position Requirements

The Department of Electrical and Computer Engineering in the Faculty of Engineering and Architectural Science at Ryerson University, invites applications for a full-time tenure track position, at the Assistant Professor level, beginning July 1, 2016, subject to final budgetary approval. **This position is an interdisciplinary position with the Department of Electrical & Computer Engineering and Ryerson's Master of Digital Media (MDM) graduate program which intersects three key areas of digital media: art & design, technology, and business & entrepreneurship.** Candidates must have a Ph.D. degree in Electrical or Computer Engineering, with an emphasis in the general area of signal processing, including multimedia, biomedical signal processing, big data analysis and machine learning. Candidates must have a demonstrated commitment to upholding the values of equity, diversity, and inclusion as it pertains to service, teaching, and scholarly, research or creative activities. Candidates must hold a strong research profile (e.g., evidence of an emerging scholarly record, ability to establish and maintain an independent, externally funded research program), evidence of high-quality teaching and student training, and a capacity for collegial service. Industrial experience would be a definite asset to this position. **This interdisciplinary positon will result in the successful applicant's home department being the Department of Electrical & Computer Engineering. The applicant will carry out an equal split of duties in teaching, research and service in his/her home department and the MDM program.**

Tenure Track Faculty Position in *Biomedical Engineering*

Position Requirements

The Department of Electrical and Computer Engineering in the Faculty of Engineering and Architectural Science at Ryerson University, invites applications for a full-time tenure track position in Biomedical Engineering, at the Assistant Professor level, beginning July 1, 2016, subject to final budgetary approval. Candidates must have a Ph.D. degree in Biomedical Engineering (with Electrical Engineering focus) or Ph.D. degree in Electrical Engineering (with Biomedical Engineering focus) or Ph.D. degree in related disciplines. In addition the following are expectations of an ideal candidate for the position.

- Demonstrate **sound** expertise in one or more of the following related areas of BME specializations: Bio robotics, Bioinformatics, Medical Devices, Physiological Modeling, Medical Imaging;
- Demonstrate **strong** experience in undergraduate course development and teaching. Ability to effectively teach key fundamental and applied BME program courses up to 3rd year;
- Strong BME research profile with evidence of peer reviewed publications/contributions and external grants (and/or participation in group grants and/or ability to attract multi-center grants). Ability to establish and maintain an independent, externally funded research program;
- Evidence of Clinical/Health research collaborations or strong potential/ability to attract Clinical/Health collaborative initiatives;
- Evidence of **strong** undergraduate guidance in Design and Innovation (Industrial experience or previous experience of guiding students and researchers will be a definite asset);
- Demonstrated (or the ability to participate in) sound leadership activities in collegial internal and external service.

Professional Engineering (P.Eng.) registration (or eligibility to register) is a necessary condition for both appointments.

Applications will be accepted until the positions are filled.

For further details and to apply, please go to http://www.ee.ryerson.ca/jobs.html

Ryerson University is strongly committed to fostering diversity within our community. We welcome those who would contribute to the further diversification of our staff, our faculty and its scholarship including, but not limited to, women, visible minorities, Aboriginal people, persons with disabilities, and persons of any sexual orientation or gender identity. Please note that all qualified candidates are encouraged to apply but applications from Canadians and permanent residents will be given priority.

NYU TANDON SCHOOL OF ENGINEERING

Several Faculty Positions in Electrical and Computer Engineering

New York University (NYU) is one of the top private universities in the United States, and the Tandon School of Engineering has the distinct history of having been known previously as Brooklyn Poly and the NYU Polytechnic School of Engineering.

The faculty and students of the NYU School of Engineering are at the forefront of the high-tech start-up culture in New York City and have access to world-class research centers in cyber security (**http://engineering.nyu.edu/crissp/**) and wireless communications (**www.nyuwireless.com**), among other areas. The School has close collaborations with the Langone School of Medicine, the Courant Institute, other schools of NYU, NYU Abu Dhabi and NYU Shanghai. The ECE Department invites outstanding applicants for tenure-track or tenured faculty appointments in the following areas: Robotics, Computer Engineering with emphasis on computer architecture and embedded systems, Electric Power Systems/Smart Grids, RF/Analog Circuits, and Signal Processing with strong links to other areas such as machine learning/big data and bioinformatics. Candidates with a strong record of interdisciplinary research and funding in emerging areas are preferred. Candidates must have a PhD degree in ECE or related disciplines and must have the ability to develop and lead high-quality research and attract external funding. Applicants should include a cover letter, current resume, research and teaching statements, and letters from at least three references. All application materials should be submitted electronically.

http://engineering.nyu.edu/facultyapp/apply/ECE101

Applications received by Jan 20, 2016 will receive full consideration.

New York University is an Equal Opportunity Employer. NYU does not discriminate due to race, color, creed, religion, sex, sexual orientation, gender and/or gender identity or expression, marital or parental status, national origin, ethnicity, citizenship status, veteran or military status, age, disability, unemployment status or any other legally protected basis, and to the extent permitted by law. Qualified candidates of diverse ethnic and racial backgrounds are encouraged to apply for vacant positions at all levels.

Faculty positions in Electrical and Computer Engineering in Africa

The College of Engineering at Carnegie Mellon University, a world leader in information and communication technology, has extended its global reach into Africa. In 2012 we became the first U.S.-based research university offering on-site master's degrees in Africa at our base in Kigali, Rwanda.

Carnegie Mellon University in Rwanda is educating future leaders who will use their hands-on, experiential learning to advance technology innovation and grow the businesses that will transform Africa.

We are seeking highly qualified candidates to join our world-class faculty, who share in our vision of developing creative and technically strong engineers that will impact society. Faculty members are expected to collaborate with industry and deliver innovative, interdisciplinary graduate teaching and research programs.

Carnegie Mellon is seeking exceptional candidates who can deliver innovative, interdisciplinary graduate programs in these areas:

- Software engineering
- Mobile and cloud computing
- Communications and wireless networking
- Cybersecurity and privacy
- Embedded systems
- Energy systems
- Image and signal processing
- Data analytics
- Applications in healthcare, agriculture, finance and infrastructure
- Innovation and technology management

Candidates should possess a Ph.D. in a related discipline and an outstanding record in research, teaching and leadership.

- Please contact us at **info@rwanda.cmu.edu** for full application requirements.
- Further information about CMU in Rwanda can be found at **www.cmu.edu/rwanda.**
- Applications should be submitted by email to **director@rwanda.cmu.edu**.

Carnegie Mellon University
Rwanda

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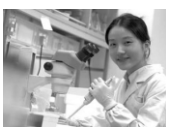

School of Chemical and Biomedical Engineering
Nanyang Technological University, Singapore

Young and research-intensive, Nanyang Technological University (NTU Singapore) is the fastest-rising university in the world's Top 20 and ranked 13th globally. NTU is also placed 1st amongst the world's best young universities.

Tenure-Track Faculty Positions at the Assistant/Associate/Full Professor level

The School of Chemical and Biomedical Engineering (SCBE) invites applicants to apply for tenure-track faculty positions at the Assistant/Associate/Full Professor level. Applicants should hold a Ph.D. in Chemical Engineering, Bioengineering, Biomedical Engineering, Food Science Technology and Engineering or a related field by the beginning of the appointment period. Candidates with post-doctoral training would be preferred.

The School is particularly interested in candidates with research interests in the following research areas:

1) Translational tissue engineering and regenerative medicine using innovative biomaterials, biomimicking nature and integrating advanced bioimaging techniques.
2) Food science and technology, specifically in the area of sustainable food sources/security and food safety through genomics and engineering system integration in urban environment.
3) Synthetic biology, specifically in the area of genome engineering, combinatorial genetics and systems biology.
4) Biotechnology, specifically in the area of infectious diseases, antimicrobial bioengineering and protein engineering.
5) Pharmaceutical engineering, specifically in the area of continuous manufacturing, crystallization and separation processes.
6) Biodevices and Bioimaging Techniques, specifically in the areas of high clinical relevance.

The candidate should have a demonstrated excellence in original research, with good publication records and the ability to teach core Chemical/Food Engineering and Bioengineering courses. Entrepreneurial qualities are also sought after.

Outstanding candidates are also welcomed to apply for NRF fellowship and Nanyang Assistant Professorship (NAP). See more at: **http://www3.ntu.edu.sg/NAP/index.html**

Responses received by 15 May 2016 would be given priority.

More information on SCBE is available at **http://www.scbe.ntu.edu.sg**

Electronic submission of application is encouraged and can be forwarded to:

Chairman, Search Committee
School of Chemical and Biomedical Engineering
Nanyang Technological University
E-mail: scbe_recruit@ntu.edu.sg

www.ntu.edu.sg

FACULTY POSITIONS

Electrical Engineering

NYU SHANGHAI

NYU Shanghai invites outstanding applications from all ranks to apply for tenure-track or tenured faculty appointments in Electrical and Computer Engineering (ECE) with special emphasis in Computer Engineering, Multimedia Analytics, Neural Engineering, and Robotics. Exceptionally strong candidates in other areas and academic ranks in ECE will also be considered. The applicants must have demonstrated abilities in both research and teaching. In describing teaching experience, candidates should identify courses they could teach both within and outside their specialty. Candidates must have completed a Ph.D. or equivalent by the time of appointment.

The terms of employment in NYU Shanghai are comparable to U.S. institutions in terms of research start-up funds and compensation, and include housing subsidies and educational subsidies for children. Faculty may also spend time at NYU New York and other sites of the NYU global network, engaging in both research and teaching.

Applications are due no later than February 1, 2016 and will be reviewed until the position is filled. To be considered, candidates should submit a curriculum vitae, separate statements of research and teaching interests (no more than three pages each), and electronic copies of up to five recent, relevant publications. To complete the online process, applicants will be prompted to enter the names and email addresses of at least three referees. Each referee will be contacted to upload their reference letter. Senior candidates are not required to submit references at this time. Please visit our website at **http://shanghai.nyu.edu/about/work/faculty-positions** for instructions and other information on how to apply. If you have any questions, please e-mail **shanghai.engineering.recruitment@nyu.edu**.

About NYU Shanghai:
NYU Shanghai is the newest degree-granting campus within the NYU Global Network University. It is the first Sino-US higher education joint venture to grant a degree that is accredited in the U.S. as well as in China. All teaching is conducted in English. A research university with liberal arts and science at its core, it resides in one of the world's great cities with a vibrant intellectual community. NYU Shanghai recruits scholars who are committed to NYU's global vision of transformative teaching and innovative research.

New York University has established itself as a Global Network University, a multi-site, organically connected network encompassing key global cities and idea capitals. There are three degree-granting campuses in New York, Shanghai, and Abu Dhabi, and complemented by eleven additional academic centers across five continents. Faculty and students circulate within the network in pursuit of common research interests and cross-cultural, interdisciplinary endeavors, both local and global.

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NYU SHANGHAI

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Faculty Positions in Electrical Engineering 2015–16

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

The Electrical Engineering (EE) Program in the Computer, Electrical, and Mathematical Sciences and Engineering (CEMSE) Division at King Abdullah University of Science and Technology (KAUST) invites applications for faculty positions at all ranks (Assistant, Associate, and Full Professors) starting from Fall 2016. Candidates applying for a position of Assistant Professor should have an excellent potential for high impact research. Candidates applying for Associate and Full Professor positions should have a distinguished track record in research and a strong commitment to service and teaching at graduate level.

KAUST is an international, graduate research university dedicated to advancing science and technology through interdisciplinary research, education, and innovation. Located in Saudi Arabia, on the western shores of the Red Sea, KAUST offers superb research facilities, generous baseline research funding, and internationally competitive salaries, together with unmatched living conditions for individuals and families. The generous social policy coupled to the top-quality research facilities have succeeded in attracting top international faculty, scientists, engineers, and students making KAUST into the only university worldwide where fundamental goal-oriented and curiosity-driven research is employed to address the world most pressing challenges related to water, food and energy sustainability as well as their impact on the environment.

More information about KAUST academic programs and research activities are available at http://www.kaust.edu.sa.

The EE program at KAUST is recognized for its vibrant research programs and collaborative environment. EE core research competencies in Energy Efficiency, Nanoelectronics and Nanotechnology, Sensors, as well as Information, Computer Vision, and Control Systems, are strongly supported by KAUST's international research collaboration network and KAUST's advanced research facilities which include the Nanofabrication, the Imaging and Characterization, and the Supercomputing Core Facilities.

More information about the EE academic program and research activities are available at http://ee.kaust.edu.sa.

Priority will be given to candidates with research interests in all the areas that represent an enhancement to the existing core research by offering complementary capabilities in the Electro-Physics and Systems tracks within the EE program:

1. Electro-Physics: Sensing devices/integrated circuits/systems, Power electronics, and Terahertz devices/systems.
2. Systems: Cyber-physical systems, Internet-of-things, and Signal processing for big data.

How to Apply:

To apply, follow the instructions outlined in the following link: **http://apptrkr.com/698062**

Where you will be requested to complete a brief application form and asked to upload - in a single PDF file - the information listed below:

- A complete curriculum vitae with a list of relevant publications
- A research plan
- A statement of teaching interests
- The names and contact information of at least 3 references for an Assistant Professor position
- A list with the names and affiliation of potential referees for Associate Professor, Full Professor, or Researchers who have equivalent positions in Industrial or National research laboratories.

Due to the high volume of applications, only applicants who submitted through the online form will be considered. Applications will be evaluated as soon as they are received, and taken into consideration until the positions are filled.

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Join Europe's top

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In 2016 the European Patent Office recruits more than 200 engineers and scientists to work as patent examiners.

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UNIVERSITY OF MICHIGAN | JOINT INSTITUTE 交大密西根学院

The University of Michigan-Shanghai Jiao Tong University (UM-SJTU) Joint Institute invites applications for tenure-track (Assistant, Associate, and Full Professor) positions, in all emerging fields related to Electrical and Computer Engineering. Candidates should hold a Ph.D. in electrical and computer engineering or a closely related field and are expected to establish vigorous research programs and contribute to undergraduate and graduate education. Salaries are highly competitive and commensurate with qualifications and experience.

The UM-SJTU Joint Institute receives strong support from both partner universities and the Chinese government. It offers B.S., M.S. and Ph.D. Programs in Electrical and Computer Engineering and related fields, and its students are among China's best. The Joint Institute models itself after the world class U.S. research universities, in terms of its tenure review and promotion system, academic environment, research program, and undergraduate curriculum. Its official language is English.

For full consideration, please send a CV, statement of research interests and teaching goals, copies of three key publications, and the names and contact information of five references, as a single PDF file, to Professor Xudong Wang, at **wxudong@sjtu.edu.cn**

Queen's UNIVERSITY

Tenure-Track Assistant Professors

Department of Electrical and Computer Engineering
Queen's University at Kingston

The Department of Electrical and Computer Engineering, in the Faculty of Engineering and Applied Science at Queen's University, invites applications for two tenure-track faculty positions at the rank of Assistant Professor in the areas of power and energy systems and electronics, as well as machine intelligence, networks, and software engineering. The preferred start date of the appointment is July 1, 2016. The successful candidates must have a PhD in Electrical and Computer Engineering or a related discipline completed at the start date of the appointment. Registration as a Professional Engineer in Canada, or eligibility to acquire registration in Canada, is an essential requirement.

Queen's University is one of Canada's leading research-intensive universities with a global reputation and a recognized leader in Canadian higher education. The Department of Electrical and Computer Engineering is medium-sized with 22 full-time and 12 cross-appointed faculty, 470 undergraduate students, and 170 graduate students.

The University invites applications from all qualified individuals. Queen's is committed to employment equity and diversity in the workplace and welcomes applications from women, visible minorities, Aboriginal peoples, persons with disabilities, and LGBTQ persons. All qualified candidates are encouraged to apply; however, in accordance with Canadian Immigration requirements, Canadian citizens and Permanent Residents of Canada will be given priority. To comply with Federal laws, the University is obliged to gather statistical information about how many applicants for each job vacancy are Canadian citizens/permanent residents of Canada. Applicants need not identify their country of origin or citizenship, however, all applications must include one of the following statements: "I am a Canadian citizen/permanent resident of Canada" OR, "I am not a Canadian citizen/permanent resident of Canada". Applications that do not include this information will be deemed incomplete.

Applicants should read the full advert at ***ece.queensu.ca*** for more details. Applications will continue to be accepted until the position is filled, however, for full consideration applications must be received by January 31st, 2016. The University will provide support in its recruitment processes to applicants with disabilities, including accommodation that takes into account an applicant's accessibility needs. If you require accommodation during the interview process, please contact Ms. Grier Owen in the Department of Electrical and Computer Engineering at ***grier.owen@queensu.ca***.

SFU SCHOOL OF ENGINEERING SCIENCE

The School of Engineering Science at Simon Fraser University, Canada, invites applications for tenure-track faculty positions in the broad areas of Computer Engineering and Microelectronics. Please visit the link below for details:
http://www.sfu.ca/vpacademic/faculty_openings/applied_sciences.html

All qualified candidates are encouraged to apply. However, Canadian citizens and permanent residents will be given priority. Simon Fraser University is committed to employment equity and to recruiting a diverse faculty and staff.

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Post your resume on the IEEE Job Site and start your job search now!

Visit the IEEE Job Site at www.ieee.org/jobs

IEEE

Faculty Position in Robotics and Control

The Department of Electrical and Computer Engineering in the College of Engineering at Michigan State University (MSU) invites applications for a tenure-system faculty position in the areas of robotics and control. Candidates must have an earned PhD in Electrical Engineering or related field. Of particular interest are candidates who demonstrate strong background in controls and apply such to emerging fields in robotics, including, but not limited to, autonomy, bio-inspired robotics, biomedical robotics, novel mobility, agricultural inspection and automation, multi-agent cooperation, human-robot interaction, and additive manufacturing. The candidate is expected to make significant contributions to research, participate in teaching and mentor undergraduate and graduate students.

This position is targeted at the junior faculty level, but senior candidates with outstanding credentials may be considered. Successful candidates are expected to leverage existing programs and facilities, and build on inter- and cross-disciplinary research strengths at MSU. Senior-level candidates should have a distinguished track record of research, innovation and sustained external funding from diverse sources.

The Electrical and Computer Engineering department has strong interdisciplinary research and educational programs on a foundation of core electrical and computer engineering disciplines and provides first-class education while engaging in research at the frontiers of knowledge. The Department has 49 faculty members, including two National Academy of Engineering members, 18 IEEE Fellows, and 13 NSF CAREER awardees. The Department has strong research programs in all major areas of electrical and computer engineering, with annual research expenditure of about $18M. Faculty in the Department are leading several federal and industry-supported centers, including the NSF Science and Technology Center BEACON, and the Fraunhofer Center for Coatings and Laser Applications. The Department has accredited B.S. degree programs in both Electrical Engineering and Computer Engineering. The current enrollment is approximately 260 full-time graduate students and 770 undergraduate students.

MSU enjoys a park-like campus with outlying research facilities and natural areas. The campus is adjacent to the city of East Lansing and the capital city of Lansing. The Lansing metropolitan area has a diverse population of approximately 450,000. Local communities have excellent school systems and place a high value on education. Michigan State University is pro-active in exploring opportunities for employment for dual career couples, both inside and outside the University. Information about MSU's dual career support can be found at **http://miwin.msu.edu/**. Information about WorkLife at MSU and the College of Engineering can be found at **http://www.egr.msu.edu/WE**.

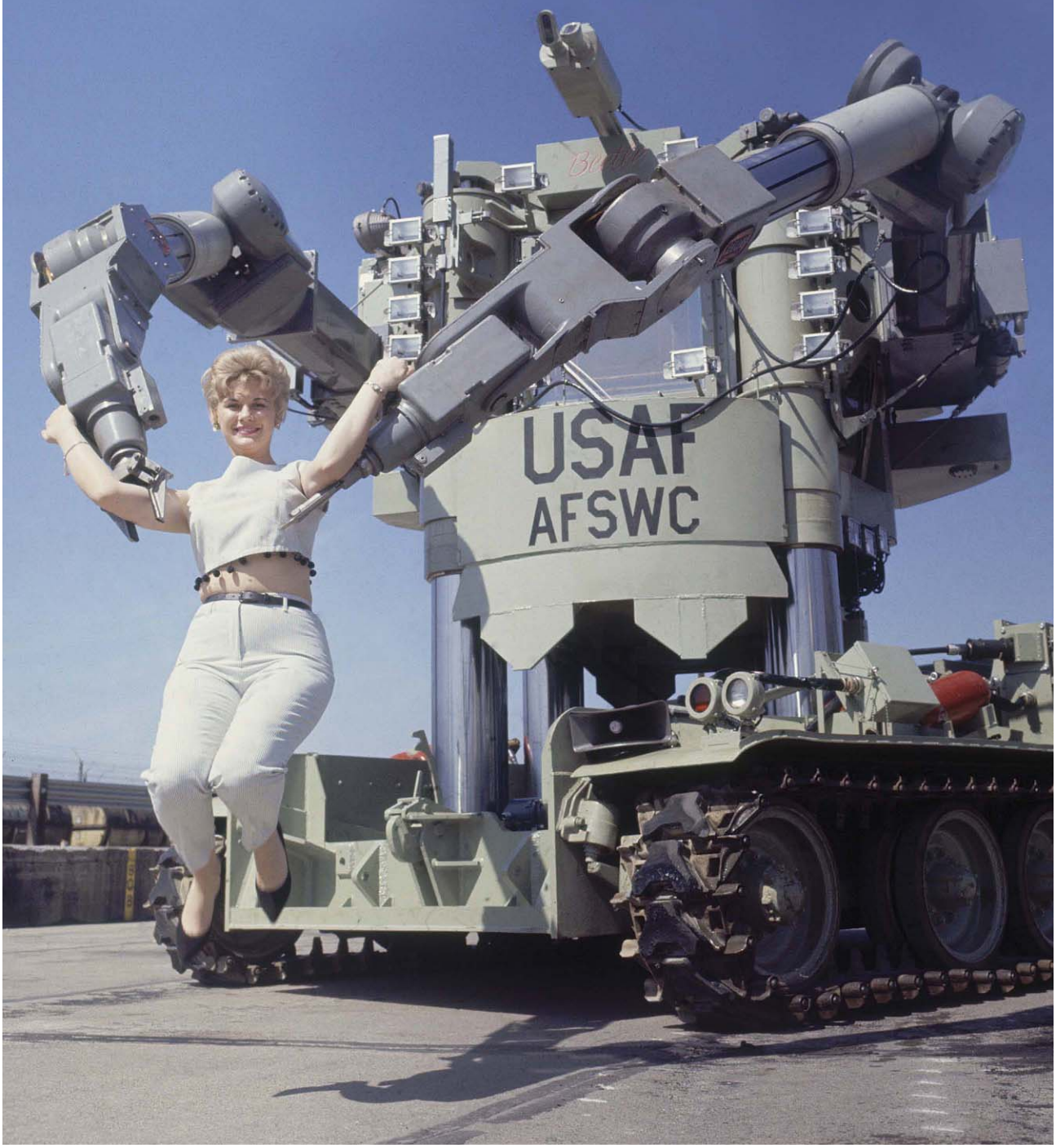
Interested individuals should submit an application for this position through: **http://jobs.msu.edu/** and refer to position **#2416**. Applicants must submit a detailed resume, a cover letter summarizing their qualifications, vision statements for teaching and research, and the names and contact information for five references. Applications will be reviewed on a continuing basis until the position is filled. For full consideration, applications should be received before February 15, 2016. Nominations or questions are welcome by contacting the search committee chair through email at **ece-robotics-facultysearch@egr.msu.edu**. The position is available on August 16, 2016.

Michigan State University has been advancing the common good with uncommon will for more than 160 years. A member of the Association of American Universities, MSU is a research-intensive institution with 17 degree-granting colleges.

MSU is an affirmative-action, equal opportunity employer. MSU is committed to achieving excellence through a diverse workforce and inclusive culture that encourages all people to reach their full potential. The university actively encourages applications or nominations of women, persons of color, veterans, and persons with disabilities.

HANDLE WITH CARE (OR NOT)

In 1962, the U.S. Air Force Special Weapons Center demonstrated the capabilities of its 77-metric-ton robot, designed to let engineers interact safely with radioactive materials (if unsafely with women). Called "the Beetle," this remote-handling vehicle was shielded for working on the engines of nuclear-powered strategic bombers, which themselves never quite materialized. The Beetle's manipulators were reportedly dexterous enough to pick up an egg without instantly scrambling it, although we're slightly concerned that the Air Force never released the next picture in this series. ■



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