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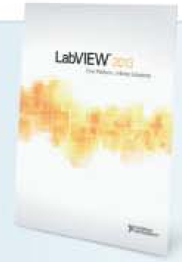

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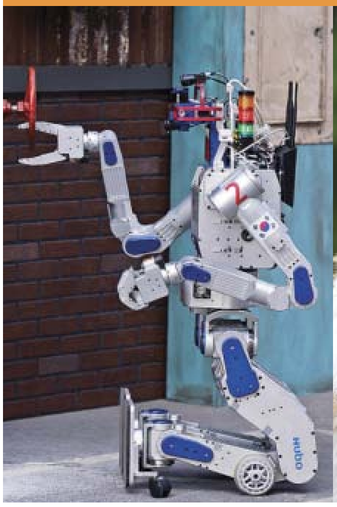

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Video: New Minidrone Cuts Through the Waves
Parrot's new hydrofoil robot does double duty as a flying and a sailing drone. It's fitted with a detachable plastic and Styrofoam hull, complete with fins that create lift as the drone picks up speed. Watch it zigzag back and forth in a rooftop pool: See http://spectrum.ieee.org/minidrone0815

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OPTICAL FIBER FOR THE MASSES Tatsuo Izawa of Tokyo's Nippon Telegraph and Telephone Corp. invented the vapor-phase axial deposition method for mass production of optical fiber, paving the way for today's telecommunications networks. His work was recently recognized with an IEEE Milestone.

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DATA TO IMPROVE LIVES From 25 to 28 October, researchers at the IEEE International Smart Cities Conference, in Guadalajara, Mexico, will discuss ways that data and sensor technology can improve manufacturing efficiency, environmental sustainability, and quality of life.

FROM LEFT: DARPA/AP PHOTO; WHISTLE LABS; KRISTEN CLARK

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BACK STORY_

What Goes Around

UNTIL THIS PAST JUNE, Sheldon Hochheiser was happily employed as the archivist and institutional historian at the IEEE History Center. "I had every intention of finishing my career here," he says. "There was only one job that would've made me leave."

That one job was at the AT&T Archives and History Center, in Warren, N.J., where Hochheiser had previously worked for 16 years. The facility houses the largest corporate archives in the United States and one of the largest in the world. "It's an extraordinary collection," says Hochheiser. "There are 8 to 9 shelf-miles of documents, 600,000 photographs, 20,000 films and videos, and 10,000 artifacts, going all the way back to Alexander Graham Bell's original patents."

After leaving AT&T in 2004, Hochheiser, who holds a Ph.D. in the history of science from the University of Wisconsin-Madison, continued to write and speak about AT&T history. Remarkably, though AT&T went through many rounds of cost cutting and downsizing in the early 2000s, the archives endured. The archives' staff, however, shrank from a peak of eight to just one person. For years, that person was George Kupczak. Several months ago, when Kupczak decided to retire, Hochheiser was asked to replace him and reclaim his former title as AT&T's corporate historian.

In this issue, Hochheiser describes a much-heralded but ultimately unsuccessful AT&T product: the Picturephone. In the photo above, taken by Kupczak, Hochheiser is shown with a version of the device belonging to the archives.

"I was there for 16 years, and I was always discovering new things, because the collection is so big," Hochheiser says. "It's going to be a lot of fun to do that again." ■

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PHOTOGRAPH BY **George Kupczak**

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Raluca Ada Popa

Popa and her former MIT thesis advisor, Nickolai Zeldovich, are working to protect people's online privacy. In "How to Compute With Data You Can't See" [p. 38], they write about some of the approaches they've pioneered, including a system for encrypting Web applications. Called Mylar, the system takes its name from the aluminized reflective material used to shield spacecraft. "We want Mylar to also be a protective layer," says Popa, who recently joined the faculty of the University of California, Berkeley.

Clark W. Gellings

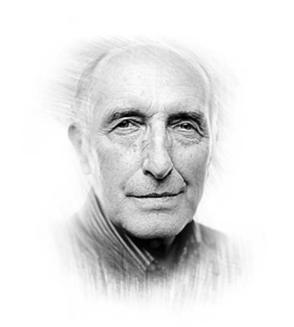
Gellings is a Fellow at the Electric Power Research Institute and an IEEE Life Fellow. In this issue, he discusses why building a global power grid makes sense [p. 44]. This is his second article for *IEEE Spectrum*. His first, published in 1981, introduced the idea of demand-side management—a now common smart-grid practice that allows electricity customers to manage their own usage. "People thought it was heretical, but the idea eventually took hold," Gellings says. "I hope that happens with this article, too."

Ellen Lee

Lee is a business and technology journalist based in the San Francisco Bay Area. This issue includes her second article in a series looking at wearable devices that are finding their way into different facets of daily life [p. 19]. While Lee says she loves discovering the innovation in wearables, she does "worry about how the data collected will be used and monitored. What happens if my entire life can be tracked through the various wearables I've worn?"

Stuart Nathan

Nathan, the features editor of *The Engineer*, published in London, is an aficionado of motor sports. He last wrote for *Spectrum* in 2013, when he covered Formula E, the all-electric racing series. In this issue he visits the team behind Bloodhound, a "missile on wheels" that Nathan saw in only a half-built state [p. 26]. Later this year its driver will test the car on a track in South Africa; in 2016, he will try to beat the world land-speed record of 1,228 kilometers per hour (763 miles per hour).



Vaclav Smil

Smil, a distinguished professor emeritus at the University of Manitoba, in Canada, has published nearly a book a year for 40 years. Known for his contrarian outlook and interdisciplinary approach, he writes about energy, globalization, technology, even the eating of meat. Bill Gates calls Smil his favorite author. Since the start of this year, Smil has been writing our "Numbers Don't Lie" column, which this month asks why people chase after wild ideas while ignoring proven ones [p. 24].

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The Pursuit of Excellence

The 2015 IEEE Honors Ceremony is a winner

GOOD AWARDS CEREMONIES have certain elements in common: They evoke in us a sense of history, of amazement–who are these dazzling people and how did they get that way?–and of pleasure at being able to share their accomplishments, even if only for a brief moment. The IEEE Honors Ceremony, held at the world-famous Waldorf Astoria hotel in New York City this past June, had all these elements, along with a good deal of fun.

The ceremony's clever conceit was that one of Thomas Edison's assistants had somehow crossed the space-time continuum to reveal that an IEEE precursor organization, the American Institute of Electrical Engineers, had held a famous dinner at the hotel in 1902. Many turn-of-the-century electrotech stars attended that fete celebrating Guglielmo Marconi and his successful shortwave radio transmission of the Morse code for *S*, of which then-AIEE president George Steinmetz remarked, "Instead of sending messages across the seas by cables, he has succeeded in sending them across empty space through the luminiferous ether."

Professional scientific and technical societies were on the rise in the late 19th and early 20th centuries, and electrical and communications geniuses like Edison, Alexander Graham Bell, and Marconi were the Silicon Valley titans of their day. They were known for their spirit and drive, their passion and intelligence.

The same was apparent at this year's honors ceremony. IEEE gave 23 recognitions for a wide range of brilliant discoveries and innovations. Notable among the recipients was Mildred Dresselhaus [above], who received IEEE's highest award, the Medal of Honor. She is the first woman to do so.

Because of her work on graphite and carbon-based materials, she is known as the "queen of carbon." The field of carbon electronics was born out of her persistent–and one has to imagine, sometimes lonely–efforts. Dresselhaus has been a tireless advocate for women in engineering and science and a mentor to myriad students. And she's a native New Yorker to boot! (Full disclosure: So am I.)

IEEE Spectrum presented awards to two important young companies we've covered: Daktari Diagnostics and O3b Networks. O3b stands for "other 3 billion," those people who have no access–yet–to the Internet.

Daktari received our Technology in the Service of Society Award, given to celebrate a technology that will greatly benefit the social good. Daktari is developing a series of simple and portable "lab in a backpack" kits to help address some of the world's most difficult health problems–like HIV, hepatitis C, and sickle-cell anemia–in those areas with the fewest health care resources. Daktari principal scientist Martina Medkova, accepting the award, said that her long days in the lab were made worthwhile knowing how much impact the kits will have.

O3b received our Emerging Technology Award, for the technology with the potential for the greatest commercial return and broad commercial impact. The company is building out a medium-Earth-orbit satellite constellation that provides instantaneous high-volume, low-latency data access to any place in the world. Accepting for O3b, CTO Stewart Sanders pointed out that he and his colleagues also felt that what was paramount was the impact the technology is having on people's lives and on entire nations. It gives users Internet access–via satellite–to health care, education, business opportunities, and social networking, access not previously available.

It's clear that engineers and technologists like these deserve the red carpet treatment as much if not more than any collection of Hollywood stars. Congratulations and thank you to all the award recipients for your difficult, risk-taking, pioneering work and outstanding achievements. –SUSAN HASSLER

IEEE

NEWS

44 MINUTES, 28 SECONDS: WINNING TIME FOR THE DARPA ROBOTICS CHALLENGE

DARPA/AP PHOTO

THE HARD LESSONS OF DARPA'S ROBOTICS CHALLENGE

What we learned from pushing 23 humanoid robots to their limit

In what must be the biggest public display of robot adoration and empathy ever witnessed, thousands cheered as the team from the Korea Advanced Institute of Science and Technology (KAIST) won the DARPA Robotics Challenge (DRC) in Pomona, Calif., on 6 June. Its robot, an adaptable humanoid called DRC-Hubo, beat out 22 other bots from six countries in a two-day competition organized with the aim of advancing the field of disaster robotics. The team from KAIST, which is in Daejeon, South Korea, walked away from the competition with the US $2 million grand prize.

DRC-Hubo's ability to switch from walking bipedally to rolling on wheels gave it a distinct advantage. Many bipedal bots had spectacular and sometimes comical falls while trying to perform tasks such as opening a door or operating a drill. But DRC-Hubo's unique "transformer" design allowed it to perform tasks faster and, perhaps more important, to stay on its feet–and wheels.

DRC-Hubo prevailed over the other robots because it finished the competition's eight tasks with time to spare: steering a utility vehicle through an obstacle course, getting out of the vehicle (which is more challenging than you might think), turning a handle and opening a door (simple for us, but hard for a robot), opening a rotating valve, using a battery-powered tool to cut a hole in a piece of drywall, inserting a plug into a wall socket, overcoming rough terrain »

HUBO THE HERO: DRC-Hubo, run by the Korea Advanced Institute of Science and Technology, can skate on wheels when it kneels.

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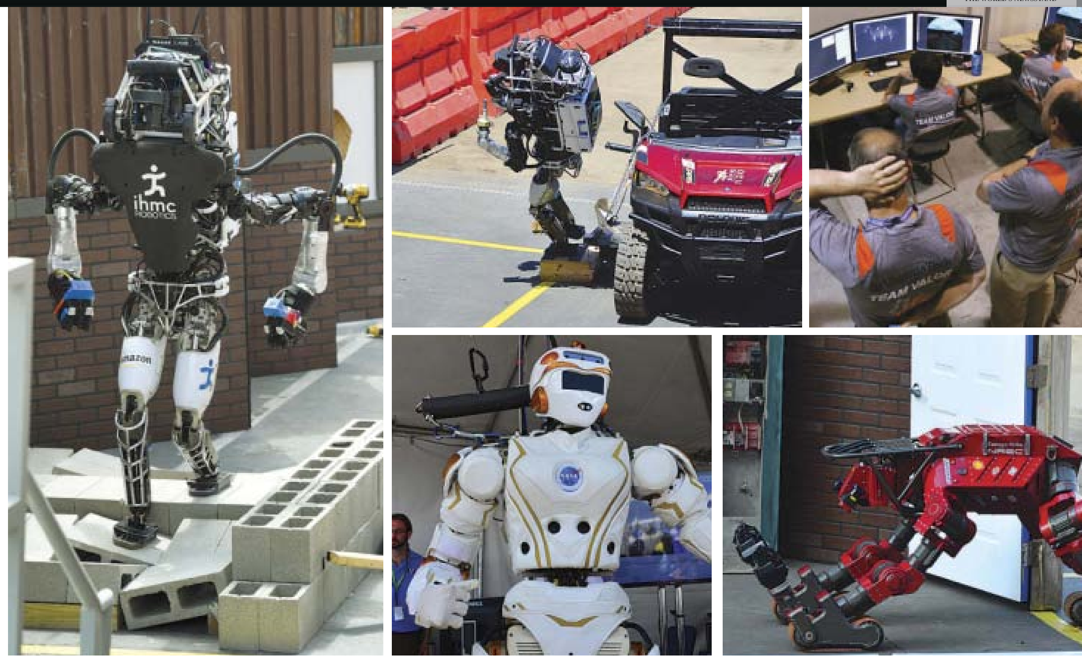

CHALLENGERS AND CHALLENGES: Team IHMC Robotics' humanoid [left] made it over some rubble. TRACLabs' humanoid fell getting out of a vehicle [top]. Teams were not allowed to see their robots directly [top right]. CHIMP [bottom right] was the only bot to pick itself up after a fall. The next challenge will center around sending a robot like Valkyrie [bottom] into space.

CLOCKWISE FROM LEFT: MARK RALSTON/AFP/GETTY IMAGES; EVAN ACKERMAN; CHIP SOMODEVILLA/GETTY IMAGES; EVAN ACKERMAN (2)

or clearing debris, and climbing a short flight of stairs.

Now that the DRC is over, what have we learned?

—ERICO GUIZZO & EVAN ACKERMAN

SOFTWARE IS A HARD PROBLEM

At an event like the DARPA Robotics Challenge Finals, it's easy to focus on the hardware because it's the part we can see. But something just as important was going on in the garages hundreds of meters away. That's where the operators ("robot drivers") received data from the robots' sensors, interpreted it, and told the machines what to do, because the drivers were not allowed to watch the robots directly during the competition.

One of DARPA's main goals with the challenge was to generate significant improvements in the ability of robots and their human operators to work in concert to perform difficult tasks, but we felt that the DRC tasks could have been—and perhaps should have been—even more challenging. For example, in the task requiring the robot to navigate over a pile of rubble, we wanted to see teams push a "go over rubble" button that would make the robot scan the terrain, compute a viable path, and then traverse the obstacles without any further assistance. Granted, autonomy is a difficult hurdle to scale, but it's key to the future of disaster-response robots because relatively untrained users will need to be able to interact with this hardware. And that means letting the robot (or more accurately, the software) deal with as many complex tasks as possible on its own.

RIGHT NOW, NOT WALKING IS A BIG ADVANTAGE

Of the top three robots in the DRC Finals, third place went to a robot that rolled on tracks, second place went to a walking biped, and first place went to a biped equipped with wheels that it could use instead of walking. During two days of watching robots fall over, we were most impressed by the ones that had the option to avoid walking.

"Bipedal walking [for robots] is not very stable yet," Jun-Ho Oh, a professor of mechanical engineering who led the KAIST team, told *IEEE Spectrum*. "One single thing goes wrong, [and] the result is catastrophic."

It's important to note that in a real disaster area, wheeled mobility may be close to useless. So despite how well the wheeled designs did at the DRC, it shouldn't minimize the future potential and value of bipedal walking. As roboticists from the Institute for Human & Machine Cognition, in Pensacola, Fla., pointed out during a postcompetition workshop, bipedal walking lets you move across areas where you only have a footstep-size safe place to move, and, unless you can fly, no other mobility design does that.

FALLING IS USUALLY OKAY…

From what we could tell, none of the teams expected their robots to survive falling as well as they did. To be honest, we were expecting shattered limbs and geysers of hydraulic fluid across the course. But with a few exceptions, the hardware stood up very well. Or rather, the hardware was stood up by a team of humans after it fell.

Take, for example, MIT's Atlas robot. It fell while getting out of the vehicle on the first day and broke its right arm. Still, after a quick tweak to the robot's software, it was able to perform the remaining tasks with only its left arm. An all-night repair session restored use of the damaged limb for the second day's tasks.

It was a bit disappointing that only one of the robots that fell over, Carnegie Mellon University's CHIMP, managed to get back up again on its own. In fact, CMU's CHIMP was the only robot that even attempted to right itself. Though it's understandable that the teams didn't want to overengineer their robots, falling happens—even to us humans—and we're much better at walking than robots are. If legged robots are ever

going to be truly effective, falling and getting up is something that they're absolutely going to have to crack.

...EXCEPT WHEN IT'S CATASTROPHIC

There were a few unlucky robots that hit the ground hard and couldn't recover. The most disastrous fall of the competition was the tumble taken by TRACLabs' Atlas robot on day two, right after it exited the vehicle it had driven through an obstacle course. On impact, there was a 2-meter-long spray of hydraulic fluid, and the robot lay there "bleeding" in a puddle of green goo until it was hoisted up and hauled away.

ADAPTATION IS A HUGE CHALLENGE

You never know what a robot is going to encounter as it traverses the scene of a disaster. But as things stand now, even tiny changes in an area's layout, or small errors in programming or commands, can lead to catastrophic failures. This is why robots are not ready for real-world disasters and won't be for quite some time.

The robots that competed in the DRC finals are more versatile and adaptable than any we've seen before. However, it's worth noting that the teams were given the choice of having the robot clear a path through debris or maneuver over uneven terrain: No legged-robot team chose the debris clearing and no wheeled-robot team tried to tackle the terrain. Teams understandably took the easiest course open to them, but in a real disaster area, a robot would likely have to deal with both rough terrain and debris. That's one downside of a competition of this type: It fosters a focus on mastering specific skills as opposed to developing the most capable and versatile robot—and those two things aren't always the same.

WHAT'S NEXT

DARPA's goal with this competition was not to present a robotic platform that could immediately be deployed into disaster areas. DARPA is all about high-risk, high-reward, long-term technological pushes, and that's the context in which the DRC should be considered.

About 10 years ago, DARPA held a Grand Challenge and an Urban Challenge for autonomous vehicles. They were successful, with a handful of self-driving cars and trucks completing the courses. Today, we're just starting to see autonomous-vehicle technology reach the cusp of mainstream adoption. So when we have real disaster-response robots in 5 or 10 years, we can thank the DRC for starting it all.

It's not likely that we'll see another humanoid challenge of the same magnitude as the DRC for some time, but there are still things to look forward to: This year, NASA will hand over several of its Valkyrie humanoid robots to university teams in preparation for a robotics challenge intended to explore the possibility of sending humanoid robots into space and, eventually, to Mars.

NEWS

COMPUTERIZED DIAGNOSTIC AIDS FAIL IN EARLY TEST

Tools for doctors get poor grades two years ahead of mandatory U.S. rollout

In just two years, computerized systems that help physicians choose diagnostic imaging tests will be mandatory for most elderly patients in the United States. But these decision-support systems fail two-thirds of the time, according to a new study published in June in *The Journal of the American Medical Association*. The study was the largest of its kind, involving more than 3,300 clinicians in eight different states and over 117,000 orders for advanced diagnostic imaging.

Use of advanced imaging such as X-ray computed tomography (CT) and magnetic resonance imaging (MRI) increased dramatically from 2000 to 2010, raising concerns about unnecessary costs and—in the case of CT—radiation exposure to patients. Making a decision about whether or not to order an imaging test is "really complex, and more and more physicians are expected to have command over an enormous volume of information," says Peter Hussey, a senior policy researcher at the Rand Corp. and the lead author of the study.

Computerized clinical decision-support (CDS) systems—software packages that help physicians choose diagnostic tests or next steps in treatment—are meant to help. The clinician enters information

JOHN LAMB/GETTY IMAGES

about the patient and the ailment, or reasons for ordering an exam. Based on a database of clinical scenarios, algorithms come up with a score for how appropriate certain diagnostic tests would be.

At the heart of CDS systems are databases of “appropriateness criteria.” These are ratings for various tests that clinicians can order based on sets of clinical scenarios. The criteria have been developed and vetted by national medical specialty societies such as the American College of Radiology (ACR).

But according to the Rand researchers, many CDS systems that use the leading appropriateness criteria don't do their job most of the time. Clinicians participating in the study ordered 117,348 diagnostic tests such as CTs and MRIs, and about two-thirds of the time the decision-support program could not rate the appropriateness of the order: It found no match between the patient's situation and a clinical guideline. “Basically it says, ‘I don't have a guideline for you. I can't help you,’ ” says Hussey.

That's a problem, because the Protecting Access to Medicare Act of 2014 says that starting in 2017, CDS systems must guide diagnostic imaging orders for Medicare patients. Medicare is the U.S. government health insurance for those age 65 and older. If CDS systems fail to provide feedback, the software might not only become a nuisance for clinicians, it might delay patient care.

The CDS researchers say the systems' shortcomings likely originate from two sources. First, the reference databases are far from complete: “There are lots of different kinds of patients with different problems, and the criteria just haven't been created for some of those,” says Hussey. Second, the software may not have been able to match the wording used by the clinicians with the wording used in the appropriateness criteria, in part because the CDS systems in the study were not well integrated with electronic health records.

> “These seem like solvable problems, but we need to get working on this pretty quickly” —Peter Hussey, Rand Corp.

“These seem like solvable problems, but we need to get working on this pretty quickly, because this is going to be mandatory in a couple of years,” says Hussey. The CDS systems used in the study were developed by various unnamed vendors and uniformly programmed with the same guidelines, most of which came from the ACR.

Some groups say they've developed software that avoids the pitfalls of those systems used in the Rand study. National Decision Support Co., in Andover, Mass., offers a system that uses the ACR's appropriateness criteria but contains twice the number of reasons for ordering exams, says Bob Cooke, vice president of marketing and strategy at National Decision Support. The additional criteria cover inappropriate reasons that clinicians might want to order an exam, so that matches are found for those scenarios too, he says.

The algorithms for CDS software are fairly simple, says Cooke. The hard part is refining and reviewing the criteria, continuously adapting the software as medicine changes, customizing the system to the varying practices in different regions, and making it work within physicians' existing computer workflow.

A complex algorithm could theoretically be created to bridge some of the gaps in clinical guidelines, but that's a solution for the distant future, Cooke says. It also makes some physicians uncomfortable. “What you would be doing is taking the work of devising the appropriateness criteria out of the hands of the professional societies,” which arrive at criteria through consensus, says Daniel Rosenthal, vice chairman of radiology at Massachusetts General Hospital, in Boston. There are many scenarios for which there is not enough evidence for a consensus, and those shouldn't—at this point—be left to a computer, he says.

The Rand study wasn't all bad news. Among the orders in which the program was able to offer feedback, there was a small increase in those rated appropriate from the beginning of the study to the end. In other words, clinicians got better at making appropriate diagnostic decisions over the course of the study. That finding is in line with those of a number of other studies on CDS, including randomized, controlled trials, says David Blumenthal, president of the Commonwealth Fund in New York City and former national coordinator for health information technology at the U.S. Department of Health and Human Services. The Rand study “may say more about the adequacy of the software used than it does about the inherent value of CDS,” he says. —EMILY WALTZ

OLD COAL'S NEW ROLE

Repurposed generators prop up grid voltage for regions rich in renewables

Environmental regulations and competition from gas-fired turbines and renewable energy sources are shutting down dozens of older coal-fired power plants across North America and Europe. But some of these aging plants' induction generators will go on spinning for years after their furnaces and turbines are scrapped. That's because operators need new ways to stabilize grids deprived of big power plants, and huge, free-spinning generators synced to a grid's AC frequency—synchronous condensers—are becoming an increasingly popular option.

The most recent such conversion is under way at the 62-year-old Eastlake coal-fired power plant near Cleveland. Here, Akron, Ohio-based utility FirstEnergy has repurposed three large generators and has two more conversions in process, due to start operating by June 2016. Several other conversions have recently been completed in California and Germany, and newly built synchronous condensers are now appearing on power grids, too.

Synchronous condensers are dynamic controllers of reactive power—AC whose current wave leads or lags the voltage wave and whose presence determines local grid voltage. Adding current to the spinning condenser's coils produces reactive power—measured in volt-amperes reactive, or VARs—and boosts grid voltage. Reduce the current and the machine absorbs VARs, depressing voltage.

Extra reactive power is often required in areas that are losing their large power plants, because millions of VARs are

A NEW LIFE: Electricians work to turn a generator into a synchronous condenser. This conversion, at a decades-old coal plant in Ohio, is likely one of many to come.

FIRSTENERGY

needed locally to boost the voltage of power transmitted from distant plants. Eastlake's synchronous converters were ordered after FirstEnergy announced plans to shutter 2,285 megawatts of coal-fired capacity—21 percent of the region's power supply—starting in 2012.

Repurposing old power-plant generators is part of a larger comeback story for a technology that seemed doomed with the advent of solid-state controllers in the 1970s. Thyristor-based static VAR compensators (SVCs) quickly conquered the market for dynamic voltage support because they produced VARs more cheaply and efficiently than synchronous condensers.

Their predecessors started making a comeback a decade ago, however, thanks to faster control systems and a growing recognition that spinning machines offered some crucial advantages over electronics. Those pros stem from a spinning rotor's mechanical and electromagnetic inertia, which make the machines more tolerant of grid disturbances.

Severe voltage drops, for example, hobble SVCs, whose reactive power output drops at double the rate of line voltage. In contrast, a synchronous condenser's spinning rotor keeps on pumping out reactive power. It will also generate real power if needed, moderating the drop in AC frequency that would result, say, from shutting down a power plant.

And the condenser's output can briefly handle several times its rated capacity for tens of seconds as its metal components heat up temporarily—behavior that is not possible for devices relying on comparatively fragile silicon switches. "Because they're iron and copper, they have a lot of overload capability. You can't overload silicon significantly," says Nicholas Miller, a power systems expert with GE Energy Consulting, in Schenectady, N.Y.

New synchronous condensers remain 10 to 20 percent more costly per VAR of reactive power capacity than an SVC, say utility planners. But converting a well-maintained generator can be quicker and cheaper.

Speed was a critical factor in the California Independent System Operator's decision to order a condenser conversion, though in a gas-fired plant instead of a coal plant, following the shuttering in 2012 of the San Onofre nuclear power plant. Without the 2,200-MW plant, located between Los Angeles and San Diego, voltage control weakened all across Southern California. "The potential for rolling blackouts in the L.A. basin was seen as a very high risk," says Chris Davidson, an electrical solutions business-development director for Siemens, which did the conversion.

Seeing what the converted condensers could do, meanwhile, inspired San Diego Gas & Electric Co. to start one of the largest deployments of new synchronous condensers. The utility expected to start spinning its first two condensers last month and plans to install five more in 2017.

And many more condensers are likely in the United States because of accelerating coal plant shutdowns. The U.S. Energy Information Agency projects that existing pollution regulations and new carbon limits could shutter about 30 percent of U.S. coal power capacity by 2020. That will leave many generators available for conversion to stabilize future power grids carrying much higher levels of wind and solar power.

Studies directed by GE's Miller for the U.S. National Renewable Energy Lab show that converted condensers could serve as a bulwark against blackouts on future grids. Though the electronic inverters built into renewable power plants can help manage grid stability far more than is appreciated today, they lack the inertia that can help get a grid through a major fault.

Miller notes, however, that synchronous condensers aren't the only potential solution. For example, gas-fired power plants can now be equipped with clutches that decouple their turbines from their generators, allowing the generator to temporarily serve as a condenser.

Another wild card to watch, says Miller, is wind power. "You can suck some of the energy out of that rotating mass temporarily and give it to the grid," says Miller.

May the smartest spinners win.

—PETER FAIRLEY

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NEWS

BAMBOO-LIKE CRYSTALS HELP TINY CHIP WIRES KEEP SHRINKING

Segmented structure could help electrons flow in future chips

COPPER CRYSTALS CONTAINED: The banded appearance of this cross section of a copper interconnect reveals a crystal structure that could carry current better in future chips.

When it comes to talk of the end of Moore's Law, transistors attract much of the attention. But the kilometers of copper wires that connect these devices on each chip have miniaturization problems of their own.

Now it seems the issue might not be as bad as engineers once thought. A team based at IBM and GlobalFoundries examined wires that will be needed for chips after the arrival of the 7-nanometer node, a manufacturing stage expected in three or so years. They found indications of a crystal structure that might actually help speed signals and reduce energy consumption.

The boost comes in resistivity, a measure of how strongly a material opposes the flow of current. Copper has a very low intrinsic resistivity. But this "bulk property" breaks down in small wires. Electrons bump up against side walls and scatter off grain boundaries, the planar surfaces inside the wire where a copper crystal changes its orientation.

The problem is only expected to get worse as copper wiring shrinks further. Adam Pyzyna of IBM's Thomas J. Watson Research Center, in Yorktown Heights, N.Y., and his colleagues tested a variety of wire sizes and shapes. Intriguingly, for certain geometries, they found it might be possible to create wires with crystalline grain boundaries that naturally run perpendicular to the length of the wire. Electrons are more likely to pass straight through such structures, which would lower the resistivity of the wires.

The effect, which was reported in June at the Symposia on VLSI Technology and Circuits, in Kyoto, is modest. The team reported that wires with this bamboo-like structure exhibited resistivity about 20 to 30 percent lower than what's been forecast by the International Technology Roadmap for Semiconductors, an industry-wide plan for future chip technology.

"This says it's not any worse than you think it's going to be and there's potential to make it better," Pyzyna says. The trick will be figuring out how to bring the structure into production, he says. A wire's resistance depends not only on how low the resistivity of the material is but also on how large the wire's cross section is. Today chip wires look like tall rectangles in cross section; they're shrunk in width so they can be packed together effectively, while they're made as tall as possible to maximize the overall area and keep resistance low. But Pyzyna and his colleagues saw the bamboo-like effect only in wires with squarer cross sections. He says it will take additional effort to determine whether it's possible to grow the bamboo structures taller to keep the resistance down.

If these structures, which were once common in larger chip wires, can be remade at smaller scales, it could also help with another problem facing interconnect: the diffusion or "electromigration" of copper ions out of the wire. Current can dislodge these atoms and propel them out of the wire and into material surrounding it, leaving behind voids that stop the flow of current. This process generally happens along grain boundaries, says Suman Datta of Pennsylvania State University. With a bamboo structure, this is less likely to occur, because the current flows perpendicular to the grain boundary and so can't as easily carry atoms to the perimeter of the wire.

Electromigration is one of the main reasons that copper wires must still shrink aggressively. Today, lining materials such as tantalum and tantalum nitride are used to prevent copper atoms from migrating out of their channels. The thickness of these liners can't be reduced, so it's the copper that must shrink.

But there might be ways to give copper breathing room. At the same conference, a team led by H.-S. Philip Wong of Stanford University discussed how graphene could be used to line the interconnect instead of tantalum. The savings for space could be drastic; a nanometers-thick layer of tantalum nitride could potentially be replaced with a liner of graphene just 0.3 nanometer thick, Wong says. That would free up space for more conductive copper, easing the miniaturization requirements.

The success of this strategy will as always come down to manufacturability. "[Graphene] has good barrier properties but it's usually quite defective," Datta says. On the other hand, he adds, "It's always a question, what graphene is useful for. Maybe this is it."

—RACHEL COURTLAND

LYNNE GIGNAC/IBM


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is one of the main principals of our work in the UAE"
Hamdan bin Mohammed bin Rashid Al Maktoum
Crown Prince of Dubai
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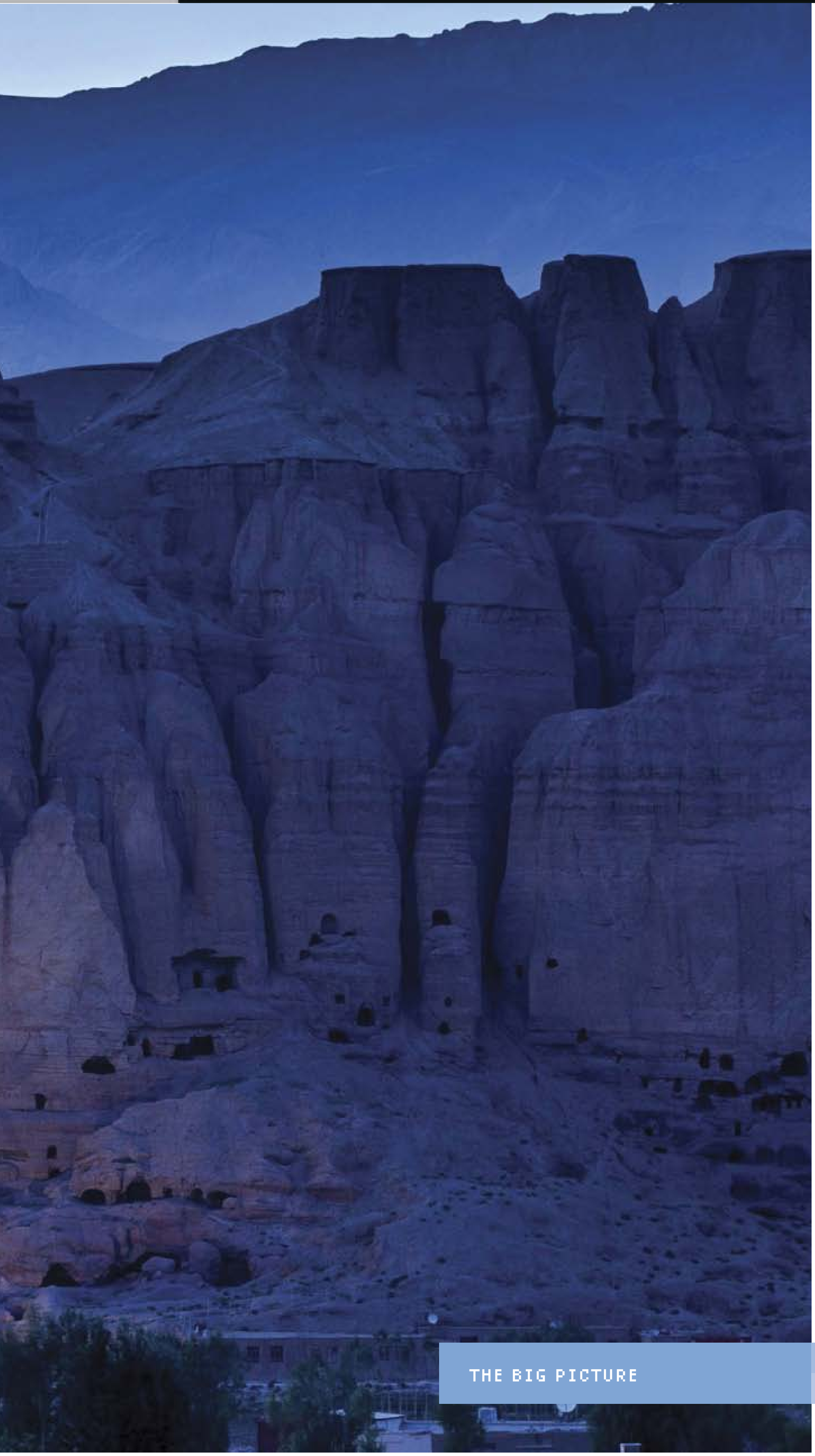

BRIGHT BEAMS BRING BUDDHAS BACK

IN EARLY JUNE, technology was used to resurrect, if only temporarily, a pair of Buddha statues that once stood in the Bamiyan Valley of Afghanistan. In place since the sixth century, the statues were blown up in 2001 by the Taliban, which had declared them false idols. After sunset on 6 and 7 June this year, the valley was lit up with a laser light projector developed by Janson Yu and Liyan Hu—a wealthy Chinese couple who've crisscrossed the globe seeking adventure in some of the world's most dangerous spots. The projector beamed 3-D images of the 53- and 35-meter-tall Buddhas right at the spots where the originals were carved into the cliff face roughly 1,500 years ago.

THE BIG PICTURE NEWS

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RESOURCES

WHISTLE LABS

77.8 MILLION

SIZE OF THE U.S. PET DOG POPULATION, ACCORDING TO STATISTA

DOG'S BEST FRIEND? THE WHISTLE CAN GIVE INSIGHT INTO A PET'S BEHAVIORAL PROBLEMS

In June, I wrote about Sproutling, a smart anklet designed for infants, in the first part of a series looking at how wearable technology is making more and more inroads into daily life. In this article, we explore Whistle, the "Fitbit for dogs."

In the United States alone, people will spend more than US $60 billion dollars on pets in 2015, according to the American Pet Products Association. Given that pet owners spend so much money, a dog wearable should come as no surprise. Skeptics may be quick to dismiss spending nearly $100 on such a wearable, but up until now, unless you're a dog whisperer, much of pet care has been guesswork, with issues mostly identified in hindsight.

For example, if Atlanta dog owner Diana Abrego had ▶

acted immediately on what Whistle was telling her, it might have saved her from a messy cleanup. Abrego was running errands one weekend last spring when an alert popped up on her smartphone: Her 3-month-old puppy, Sara, which she and her husband had adopted a month before from a shelter, had reached her "daily activity goal."

Sara, a hound-and-retriever mix, was wearing Whistle, a round, metallic waterproof tag about the circumference of a silver dollar, on her collar. The Whistle tracks how much a dog plays, runs, and rests each day using a 3-axis accelerometer. Whistle's algorithms have been designed to detect the difference between running, active playing, and resting. (The battery needs recharging about once a week.)

That activity data is sent to a smartphone app via either a Wi-Fi or Bluetooth connection. The app calculates how much exercise a dog should get each day, based on its breed, age, and size, and it also allows owners to track medication and log meals. In Abrego's case, the alert indicated that Sara had reached her target of 60 minutes of activity for the day. In fact, the app showed that she had exceeded it by 30 minutes.

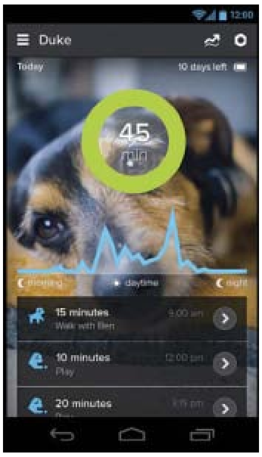
Sure enough, when Abrego returned home, it was clear how her puppy had gotten her exercise. "From the moment we left her until 5 minutes before we returned home, she had been running around nonstop," Abrego recalls. The puppy had torn apart her pee pad and then urinated on top of the shredded bits. She had also ripped apart her bed. "It was a mess."

Abrego laughs about the incident now, but it shows how a wearable device can remotely monitor the well-being of a dog and alert owners to problems. In another instance, an owner was able to intervene and take her dog to the veterinarian after the Whistle showed that her dog was unusually sluggish. It turned out the dog had been bitten by a snake. Whistle's uses have also been extended to veterinary schools and pharmaceutical companies. In a partnership with North Carolina State University's College of Veterinary Medicine, the Whistle is helping researchers track canine epilepsy, monitoring dogs before, during, and after a seizure.

The accumulation of data on the dog's daily routine offers better clues for understanding it, says Whistle Labs' CEO, Ben Jacobs: "We're using technology to provide a voice for these animals," he says.

In January, the San Francisco startup also acquired Tagg, a wearable that uses cellular and GPS technology to track a dog's whereabouts. Dog owners establish a "home base" for the dog, and if the dog wanders away, they're alerted via a text message or e-mail and can use a map to pinpoint their dog's location.

As for cats, Whistle Labs has contemplated developing a similar tracker—company cofounder Kevin Lloyd is actually a cat person—but it has not yet come up with a suitable design. Somehow it seems appropriate that felines may be the last resistors in our march toward an always connected, wearable world. **—ELLEN LEE**



INTERNET OF DOGS: Fitted to a collar [top], the Whistle tracks your pet's activity and reports via a smartphone app.

TAKE YOUR PI FOR A RIDE

SPINNING UP A RASPBERRY PI-BASED CYCLING COMPUTER

LAST MONTH, PAUL WALLICH BROUGHT YOU a bicycle-mounted lidar for detecting cars approaching from behind. I'm continuing the cycling theme this (Northern Hemisphere) summer with a bike computer designed for middle-aged eyes. ● Like many people my age, I struggle to see the tiny display of a typical bike computer: I can't very well put on my reading glasses while I'm pedaling. Also, I enjoy exploring unfamiliar roads, which makes navigation a challenge because I don't carry a smartphone. My old CatEye cycling computer, which just reports how fast I'm going and how far I've gone, is no use at all in that regard. ● There are, of course, commercial products that could help me navigate on my bike, but they are expensive, and their compact displays are, again, difficult to see—even for youthful eyes if you're out in direct sunlight. ● These issues led me to explore a DIY solution. My concerns about sunlight visibility meant my DIY cycling computer would need a reflective display of some type, but an alphanumeric LCD panel of the usual sort wouldn't cut the mustard. I wanted really big numbers displayed. I also wanted it to be able to show a map bigger than a postage stamp.

LEFT: WHISTLE LABS (2); RIGHT: DAVID SCHNEIDER

The answer turned out to be already in my possession: A Kindle Touch e-reader. It was the perfect size—big enough to display a lot of information at once in a large font and to show me a decent chunk of a map without scrolling. Its E Ink display is clear and crisp even in bright light. And the price was right. The only problem was that I couldn't hack its software to make it do what I wanted.

This wasn't just a technical issue; it was a legal one. Modifying such a gadget to operate in ways other than the manufacturer intended—even if you own the device—flirts with provisions of the Digital Millennium Copyright Act, bizarre as that may seem. The U.S. government (for odd reasons, specifically the Librarian of Congress) doesn't want you to have full control of the software on your phone, tablet, or e-reader—even if it's open source. But after some pondering, I realized that I could make the Kindle serve my needs without touching a single line of code running on it.

The trick was to use the Kindle's "experimental" Web browser, allowing me to put the brains of the computer elsewhere, in this case on a US $20 Raspberry Pi Model A. The Raspberry Pi, being cheap and open, was perfect for the job. By plugging a suitable Wi-Fi dongle ($12) into its USB port, I could make it into a Wi-Fi access point. Run a Web server on the Pi and it can send HTML of your choosing to the Kindle to display.

My system consists of three parts: the Raspberry Pi and its battery (which reside in the bike's saddlebag); a small PC board of my own design (which carries a $30 GPS module and plugs into the Pi); and a Kindle Touch (mounted on the handlebars using bits of foam pipe insulation and a few rubber bands).

Two reed switches mounted to the frame of my bike sense wheel rotation and pedal cadence by virtue of magnets attached to a spoke and to the inner chain ring. These switches are electrically connected to pins on the Raspberry Pi's GPIO (general purpose input/output) port, allowing the Pi to know how fast the wheels and pedals are turning.

The list of software that I needed to install and configure on the Pi to make all this work is not short. It includes hostapd, which allowed me to transform the Pi into a wireless access point, thanks to some helpful online instructions. I also installed Flask, a lightweight framework for writing Web applications in Python (again, following helpful leads on the Web). But it didn't end there. For example, I needed another program, gpsd, to parse the GPS data coming in from my little add-on board. And there were JavaScript libraries as well to load, including Leaflet, which allowed me to add a nifty mapping feature to my cycling computer.

Eventually, I was able to get my Flask app to run automatically when the Pi powered up and have the Pi act as a captive portal, meaning that it served up my app's output no matter which URL the Kindle's browser was pointed to.

Next, I had to write a cycling-computer Web app that would look good on the Kindle's E Ink display. There were two notable complications. One arose because of the way E Ink works. It's very susceptible to ghosting, where pixels don't properly switch to a new state, so Amazon.com's engineers arranged for the Kindle's browser to cycle the entire display from black to white and back again when a new page loads. This initially made for awkward flickering, because my initial app sent a new page with updated values every second. The solution was to use what's known in Web-development circles as Ajax techniques to update just the necessary elements without sending a whole new page and triggering a refresh.

Another twist peculiar to the Kindle is that when it connects to a new access point, it immediately tries to reach Amazon. If it doesn't get the right response, it won't treat the access point as valid. The solution was simple: Have the Pi supply the Kindle with the short response it was expecting from Amazon.

In the end, I managed to pull together a system that shows distance, instantaneous speed, average speed, cadence, elapsed time, and clock time all at once, with digits large enough to read without squinting. Swiping and pressing buttons brings up other screens that offer such goodies as real-time mapping and logging. Even if you have to buy a Kindle for this project, the cost of the hardware involved is probably less than half what you'd be paying for a commercial unit with these capabilities.

—DAVID SCHNEIDER

BIKE BYTES

DAVID SCHNEIDER (4)

BUILDING THE BIKE COMPUTER required making hardware upgrades to a Raspberry Pi, adding GPS and Wi-Fi [top]. With its battery pack, the computer fits easily into my rear saddlebag [second from top]. Reed switches and magnets detect how fast the pedals and wheels are turning [bottom two photos].

ENGAGING WITH THE SCI-TECH OF SCI-FI

RESEARCHERS CAN LEVERAGE MOVIES LIKE *SELF/LESS*

TECH TRANSFER: Ben Kingsley [rear] and Ryan Reynolds play the combined role of a wealthy man seeking immortality.

Last month, the science-fiction movie thriller *Self/Less* opened in the United States, and the film is currently rolling out worldwide. Starring Ryan Reynolds and Ben Kingsley, *Self/Less* is premised on a brain-scanning immortality technology that allows a person's consciousness to be transferred to a new body.

These days, this kind of movie begets a sci-tech charm offensive: Modern audiences pay more attention to the believability of science-fiction flicks than was once the case. Thanks to the Internet, if someone can explain why a movie's ideas are ridiculous, word gets around. Consequently, moviemakers and studios have increasingly been using researchers as consultants during production or to explain a film's details and implications to the public after the fact.

For *Self/Less*, the movie's studio, Focus Features, enlisted two University of Arizona associate professors and IEEE senior members: neuroscientist and electrical/computer engineer Charles Higgins and physicist and roboticist Wolfgang Fink.

Higgins earned his Ph.D. in electrical engineering from Caltech in 1993 and did a neuroscience postdoc there from 1996 to 1999. Part of his research is studying insect brains as an entryway to understanding more complex brains—specifically, how insects combine disparate information to create navigational intelligence. He's also working on a consumer device to monitor brain waves during sleep and biomedical indicators of disease.

Higgins is up front that the immortality tech in *Self/Less* is still sci-fi: "To scan a person's intelligence would probably require a complete 3-D structural and functional study of all 100 billion neurons," he says. "As far as transferring consciousness to another living body, due to the differences between each person's brain, you'd need a clone of someone's brain to have a ghost of a chance." But, Fink adds, "once you buy into the underlying premise that you can transfer consciousness, then the rest of movie flows quite logically. It doesn't tank."

Fink earned a Ph.D. in theoretical physics from the University of Tübingen, in Germany, in 1997. He uses both machine and neural learning in his research, which involves artificial vision and applying it to areas such as autonomous robotic space exploration. Currently, robot missions are closely directed from Earth. But with a truly autonomous space probe or rover, as Fink envisions, algorithms would decipher camera images to gauge the best area to explore. "The idea is to instill a reasoning process into the machine to make those decisions," says Fink, "but that gets us into the realm of sentient systems."

How does this tie back to *Self/Less*? "The movie addresses the self versus the nonself," says Fink. "Just as implants might one day be able to replace dysfunctional brain tissue, so would you also be able to create an implant that might suppress moral judgment, say, to create the perfect soldier. Where do you stop being in control, and where does the machine take over? With an artificial neural network system, how much are you still yourself, and what's the chance that someone—or something—else is controlling you?"

Focus Features did not pay Higgins and Fink, but they were flown to Los Angeles to participate in press conferences and contribute to the electronic press kit. So how did two researchers get involved with a movie studio?

While some researchers are paid consultants for television and movie productions, a larger number volunteer their advice in the name of greater scientific literacy through organizations such as the National Academy of Sciences' Science & Entertainment Exchange. This connects screenwriters and producers who have technical questions with experts who can answer them. The pop culture tie-in helps researchers reach a broader audience—particularly useful for those who want to position their research as startup ready. Higgins (who has also advised on films such as *Elysium* and the remake of *Total Recall*) and Fink connected with Focus through ZoomWerks Media, a Pasadena, Calif., publicity firm specializing in science and entertainment. Says Higgins, "By doing interviews and relating real science to science fiction, I believe that we are connecting better with people than academics typically do." —**SUSAN KARLIN**

FOCUS FEATURES

RESOURCES_GEEK LIFE

CHINA'S MAKER SCENE IS EXPLODING

RAPID GROWTH IN MAKER SPACES MAY HERALD A TECH RENAISSANCE

CAPTURING COMMUTER POWER: Maker Liu Zhaoying holds up a prototype of a gadget designed to harvest energy from the motion of standing passengers on trains and buses.

NANJING MAKER SPACE

In May, Shanghai hosted the inaugural CES Asia consumer electronics show. CES Asia is a spin-off of the well-known International CES event that takes place every January in Las Vegas. The Consumer Electronics Association, which owns both shows, believes that CES Asia could one day rival—and even eclipse—its American counterpart. For now, though, CES Asia is a much smaller affair, with a fraction of the exhibitors and events of International CES.

But despite the smaller scale, there were interesting things to be seen, in particular one event on the last day. Nervous makers from spaces and universities located in Shanghai and surrounding cities trooped onstage to make presentations to a panel of judges. It was a scene that would have been familiar in other countries, but it was something new to China: the country's first maker contest. And it's unlikely to be the last, as the number of Chinese maker spaces is growing rapidly. "Domestic maker spaces started in 2010, and it was a very niche activity," said Rocky Zheng, head of the Nanjing Maker Space, through a translator, before the judging began. "Until 2013, China had only 15 spaces. Then it began booming. By April 2014, there were over 100 spaces."

Projects presented during the contest included a headset for bathing dry eyeballs in a vapor containing traditional Chinese medicines; a device for harvesting energy from straphangers swaying back and forth as buses and subway trains lurch along their routes; a system that would allow users to have their text messages shown at the bottom of a television screen; reformulated pottery clay that could be extruded from a modified 3-D printer capable of producing complex ceramic designs; and an electronic lock that opened using coded light signals from a smartphone app. The winner was a team from Shanghai that developed a system for warning drivers when they stray outside their lanes.

Growth in maker spaces will be fueled by the Chinese Ministry of Industry and Information Technology's (MIIT) recent embrace of makers and small tech startups. Among other efforts, the MIIT is creating an online platform for makers to exchange information and raise money via crowdfunding.

The government's interest is clear: Some of the official speakers at the contest seem to view makers largely as nascent business entrepreneurs, and maker spaces as incubators primed to feed innovative product ideas directly to industry. This was reflected in a second round of the contest that followed the maker presentations, in which teams from small (and not-so-small) companies presented commercial product ideas such as an automated frying pan or smart systems for reducing office energy use—more the kind of thing you'd see at a Y Combinator–style event rather than a maker contest.

But several speakers from the maker community were quick to make the point that while products can come out of maker spaces, it would be a mistake to view them, and the people working in them, so narrowly: "We try to best turn our creativity and hobbies into reality. We may be able to commercialize in some areas, but in others we are simply playful in our effort. Makers go beyond the scope of entrepreneurs," said Nanjing Maker Space's Zheng.

Currently, the goal of the Chinese maker movement is to create spaces in the provinces, spreading them out from their current concentration around cities such as Beijing, Shanghai, and Shenzhou. If this can be done in the maker spirit espoused by Zheng, China could indeed be seeding a creative tech renaissance. **—STEPHEN CASS**

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WHEN INNOVATION FAILS

MODERN SOCIETIES ARE OBSESSED WITH INNOVATION. In June 2015, Google searches returned 389 million hits for "innovation," easily beating "terrorism" (92 million), "economic growth" (91 million), and "global warming" (58 million). We are to believe that innovation will open every conceivable door: to life expectancies far beyond 100 years, to the merging of human and machine consciousness, to essentially free solar energy.

This uncritical genuflection before the altar of innovation is wrong on two counts: It ignores those big, fundamental quests that have failed after spending huge sums on research. And it has little to say about why we so often stick to an inferior practice even when we know there's a superior course of action. • The fast breeder reactor, so called because it produces more nuclear fuel than it consumes, is one of the most remarkable examples of a prolonged and costly innovation failure. In 1974 General Electric predicted that by 2000 about 90 percent of the United States' electricity would come from fast breeders. GE merely reflected a widespread expectation: During the 1970s, the governments of France, Japan, the Soviet Union, the United Kingdom, and the United States were all investing heavily in the development of breeders. But high costs, technical problems, and environmental concerns led to shutdowns of British, French, Japanese, U.S. (and also smaller German and Italian) programs, while China, India, Japan, and Russia are still operating experimental reactors. After the world as a whole has spent well above US $100 billion in today's money over some six decades of effort, there is no real commercial payoff.

Other promised fundamental innovations that still are not commercial concerns include supersonic passenger flight, magnetic levitation trains, and thermonuclear energy. The last one is perhaps the most notorious example of an ever-receding innovative achievement.

The second category of failed innovations—things we keep on doing even though we know we shouldn't—range from quotidian practices to theoretical concepts. Why are we boarding flights from back to front when we know of better ways? And there's no need to go for the best but organizationally tricky Steffen method, in which passengers fill a plane from the back to the front, windows first, skipping every other row so that everyone has more space to get settled. We might do even better by seating people in a reverse pyramid, alternately boarding them at the back and at the front simultaneously (spreading things out to minimize bottlenecks), or simply by abolishing assigned seating.

Why do we keep imposing "daylight saving time" changes semiannually when we know they don't really save anything?

And why do we measure the progress of economies by gross domestic product? GDP is simply the total annual value of all goods and services transacted in a country. It rises not only when lives get better and economies progress but also when bad things happen to people or to the environment. Higher alcohol sales, more driving under the influence, more accidents, more emergency-room admissions, more injuries, more people in jail—GDP goes up; more illegal logging in the tropics, more deforestation and biodiversity loss, higher timber sales—again, GDP goes up. We know better, but we still worship high annual GDP growth rate, regardless of where it comes from.

Why do we love wild and crazy innovation when there is so much practical innovation waiting to be implemented? Why do we not improve the boarding of planes rather than delude ourselves with visions of hyperloop trains and eternal life? ■

PHOTO-ILLUSTRATION BY Sean McCabe

WE'RE ALL DATA GEEKS NOW

Data science is going to be as foundational to education as English... [It] doesn't belong in the business school. Everybody should take data science. *—Jennifer Priestly, Kennesaw State University*

WHEN GARTNER RELEASED ITS ANNUAL Hype Cycle for Emerging Technologies for 2014, it was interesting to note that big data was now located on the downslope from the "Peak of Inflated Expectations," while the Internet of Things (often shortened to **IoT**) was right at the peak, and data science was on the upslope. This felt intuitively right. First, although big data–those massive amounts of information that require special techniques to store, search, and analyze–remains a thriving and much-discussed area, it's no longer the new kid on the data block. Second, everyone expects that the data sets generated by the Internet of Things will be even more impressive than today's big-data collections. And third, collecting data is one significant challenge, but analyzing and extracting knowledge from it is quite another, and the purview of data science. ● Just how much information are we talking about here? Estimates vary widely, but big-data buffs sometimes speak of storage in units of **brontobytes**, a term that appears to be based on *brontosaurus*, one of the largest creatures ever to rattle the Earth. That tells you we're dealing with a big number, but just how much data could reside in a brontobyte? I could tell you that it's 1,000 **yottabytes**, but that likely won't help. Instead, think of a terabyte, which these days represents an average-size hard drive. Well, you would need 1,000,000,000,000,000 (a thousand trillion) of them to fill a brontobyte. Oh, and for the record, yes, there's an even larger unit tossed around by big-data mavens: the **geopbyte,** which is 1,000 brontobytes. Whatever the term, we're really dealing in **hellabytes**, that is, a helluva lot of data. ● Wrangling even petabyte-size data sets (a petabyte is 1,000 terabytes) and **data lakes** (data stored and readily accessible in its pure, unprocessed state) are tasks for professionals, so not only are listings for big-data-related jobs thick on the ground but the job titles themselves now display a pleasing variety: companies are looking for **data architects** (specialists in building data models), **data custodians** and **data stewards** (who manage data sources), **data visualizers** (who can translate data into visual form), **data change agents** and **data explorers** (who change how a company does business based on analyzing company data), and even **data frackers** (who use enhanced or hidden measures to extract or obtain data).

But it's not just data professionals who are taking advantage of Brobdingnagian data sets to get ahead. Nowhere is that more evident than in the news, where a new type of journalism has emerged that uses statistics, programming, and other digital data and tools to produce or shape news stories. This **data journalism** (or **data-driven journalism**) is exemplified by Nate Silver's FiveThirtyEight site, a wildly popular exercise in **precision journalism** and **computer-assisted reporting** (or **CAR**).

And everyone, professional and amateur alike, no longer has the luxury of dealing with just "big" data. Now there is also **thick data** (which combines both quantitative and qualitative analysis), **long data** (which extends back in time hundreds or thousands of years), **hot data** (which is used constantly, meaning it must be easily and quickly accessible), and **cold data** (which is used relatively infrequently, so it can be less readily available).

In the 1980s we were told we needed cultural literacy. Perhaps now we need **big-data literacy**, not necessarily to become proficient in analyzing large data sets but to become aware of how our everyday actions–our **small data**—contribute to many different big-data sets and what impact that might have on our privacy and security. Let's learn how to become custodians of our own data. ■

ILLUSTRATION BY **Greg Mably**

BY STUART NATHAN

BUILDING BLOODHOUND: THE FASTEST CAR IN THE WORLD

Jets, rockets, and computer models will help a British team break 1,600 km/h

IN A SUBURB OF BRISTOL, IN WESTERN ENGLAND, not far from the Welsh border, a band of engineers are building a machine that they hope will make the biggest jump in the century-long history of the official world land-speed record, taking it from a smidgen above the speed of sound to 1,600 kilometers (1,000 miles) per hour. That's roughly the cruising speed of a fighter aircraft, but it's considerably harder to achieve at ground level, where the atmosphere is far thicker. And there's the not-insignificant danger that the vehicle will end up plowing into the ground. • Even in the complicated business of breaking such speed records, Bloodhound represents a remarkable array of firsts in terms of technology, engineering techniques, and propulsion systems, all set to send the missile-shaped car down a nearly 20-km-long racetrack in the South African desert toward the end of this year. Perhaps the most striking of those firsts is the project's method of verifying the safety of the design. To a degree that would be unthinkable today, earlier record attempts relied on overengineering, best-guess estimates, intuition, and sheer luck. Earlier generations of engineers would often discover a car's limits with destructive testing–running it until it broke. Now modeling and data acquisition, the preferred tools for designing both aircraft and cars, are making headway in this most extreme of sports. Bloodhound is the first project of its kind to apply them. By the time the car makes its great bid for the record in South Africa, it will have done the run 1,000 times in silico.

THE PROJECT IS TAKING SHAPE in what's known as the Doghouse, a hangarlike space that is divided down the middle. To the right as you enter is a structure that will house the control center, recovery vehicles, and testing rigs, along with the "show car," a full-scale model that has become a familiar sight at industrial exhibitions around the United Kingdom during the seven years of the project. On the left is the growing bulk of the thing itself, whose full name is Bloodhound SSC (for "supersonic car"). It was just over halfway finished when this article was being written.

At the center of Team Bloodhound are the current holders of the land-speed record: driver Andy Green (a fighter pilot now serving as a wing commander with the Royal Air Force), project director Richard Noble, and veteran aerodynamicist Ron Ayers. In 1997, Green became the first person to break the sound barrier on land, setting a record of 1,228 km/h (763 mph) in a car called Thrust SSC as it raced over the Black Rock Desert in Nevada. Noble set the previous record, hitting 1,019 km/h (633 mph) in a car named Thrust II in 1983. As with all these trials, the speeds are an average of two runs in opposite directions within a set time limit.

Project Bloodhound's first goal is to break Green's existing record before the end of 2015. The second is to take the record into new territory, hitting 1,600 km/h in 2016, after an engineering review of the 2015 runs and a possible rebuild. The third is to motivate more young people to study engineering, just as the Apollo program did for Noble's generation in the 1960s and 1970s.

The last of these goals came about almost by accident. Bloodhound's predecessor, Thrust SSC, was powered by two jet engines–Rolls-Royce Spey turbofans, taken from a retired RAF Phantom fighter-bomber. Noble and Green knew that this arrangement wouldn't be enough to set a new record. Two engines would be too heavy, and the elderly Speys wouldn't have the necessary power. At the outset of the project, the only single jet engine with the power-to-weight ratio needed was the Rolls-Royce Eurojet EJ200, the power unit for the Typhoon fighter. And even then, it was obvious that to send it through the sound barrier the effort would have to use a second propulsion system–a rocket.

But you can't buy a new EJ200 on the open market, and you won't find any surplus units on eBay. The only way to get your hands on one is to ask very nicely. So in 2007 Green and Noble approached the U.K. Ministry of Defense, asking to do just that. They were told they could borrow one, but only if they combined the project with an educational effort.

SOME ASSEMBLY REQUIRED: The Rolls-Royce jet engine is eased into place [top, bottom left]. The Jaguar V8 engine [middle] will pump hydrogen peroxide to the rocket (not shown). Driver Andy Green sits in an armored cockpit [right] paneled with displays, including one of his own design.

PREVIOUS PAGES AND THESE PAGES: STEFAN MARJORAM (5)


WLL 2000KG

As a result, the Bloodhound show car has toured hundreds of schools in the U.K. It has also visited many South African schools. Meanwhile, the car's runs will be public to an unprecedented extent, with data from onboard sensors streamed on the Internet in real time.

IN ANOTHER FIRST, Bloodhound carries three engines. From standstill to about 650 km/h (400 mph), the EJ200 takes the strain. Above this speed, a set of rockets supplied by a Norwegian company, Nammo, will add their thrust. These are hybrid rockets, burning solid fuel–a synthetic rubber compound–using high-test hydrogen peroxide (HTP) as the oxidant. The pump squirting the HTP into the combustion chamber will be driven by the third engine, an eight-cylinder, 5.0-liter, supercharged internal-combustion engine normally found in a Jaguar.

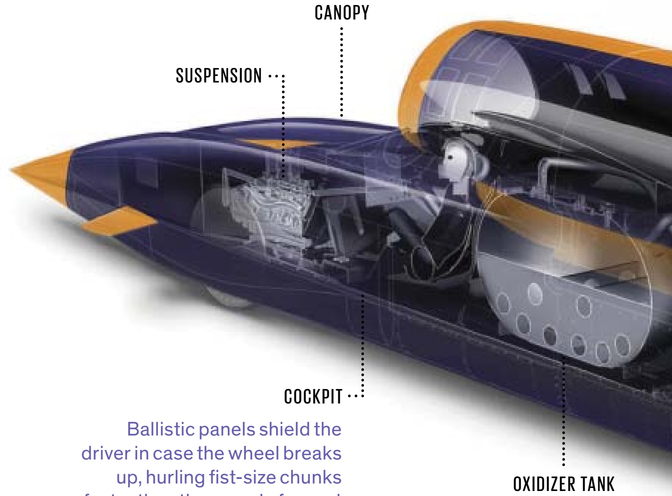
This design combines power and controllability. The jet can be throttled up and down–an operation with which Green, as a fighter pilot, is very familiar. The hybrid rocket is also throttleable, to an extent: Its thrust is proportional to the pressure with which the HTP is pushed into the combustion chamber, and the Jaguar engine doing that can provide a range of output to achieve this. In practice, Green won't adjust the flow of oxidizer after he fires the rocket. He can shut off the HTP, though, thereby shutting down the rocket.

Bloodhound also has three braking systems. The first to deploy will be a pair of air brakes, which stick out from the sides of the car close to its rear end. These large perforated panels are operated pneumatically and are mechanically linked so that both always open to the same degree. They will slow the car down to about 1,080 km/h (670 mph), at which point Green will release two drag parachutes, similar to those used by some aircraft, to reduce speed to about 320 km/h (200 mph). From here, the car will be brought to a stop using conventional brakes attached to the front wheels.

The wheel brakes are a good example of how the demands of the project affect development. Although they will be used only in the last stages of stopping the car, the brake discs spin along with the wheels, and therefore at peak speed they will be moving at about 10,500 revolutions per minute. The team tested the brake discs used on the Typhoon fighter, but these couldn't manage the job. Neither could any carbon-fiber brake disc. Even the hardiest model put through a spin test shattered into tiny pieces as it neared the vital speed. "We had to vacuum all the bits and dust out of the test rig," recalls systems engineer Joe Holdsworth.

The only brake discs that can cope with the strain are steel, which is likely to distort but is cheap enough to be replaced if necessary.

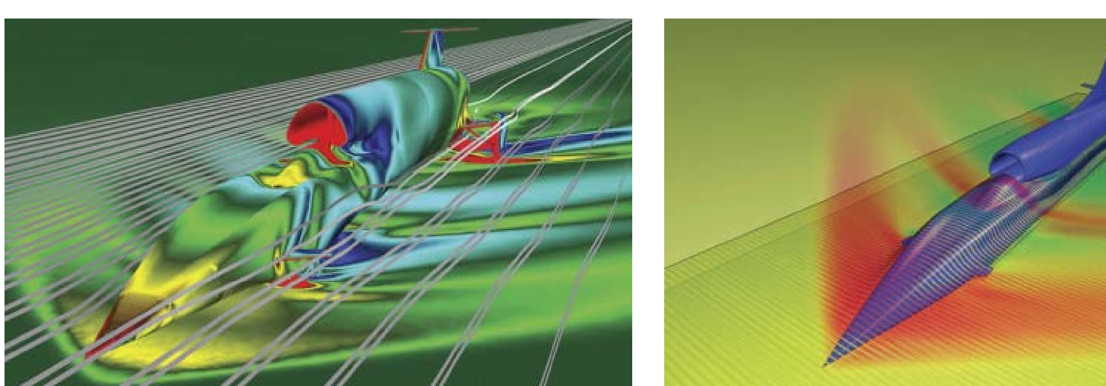
This was one of the very few times these engineers used destructive testing to design something for Bloodhound. In marked contrast to those attempting most of the previous



Ballistic panels shield the driver in case the wheel breaks up, hurling fist-size chunks faster than the speed of sound.

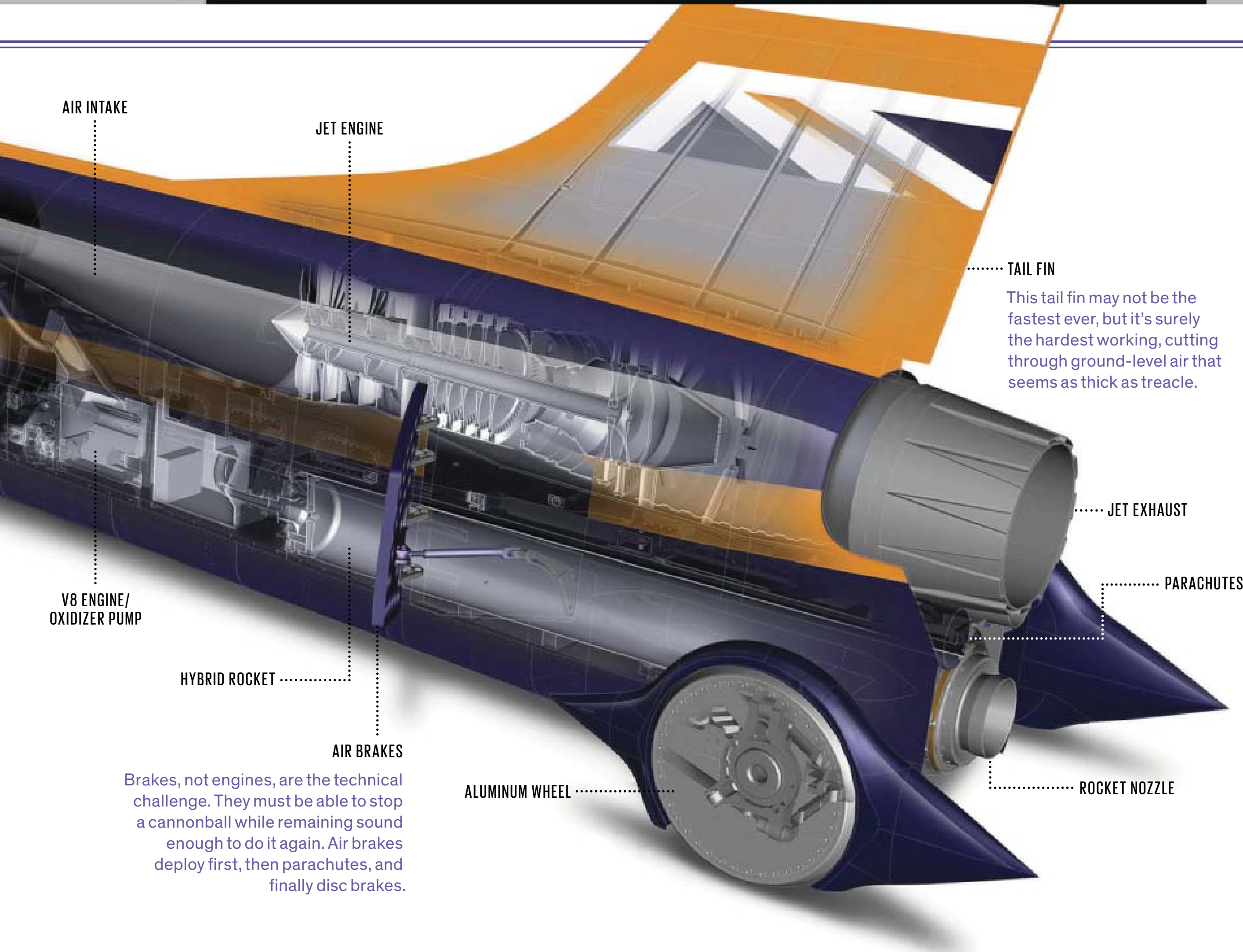
MY JET HAS A *ROCKET*

The jet gets the car moving and the rocket sets the records; both are packed among fuel lines that themselves require a pump powered by a V8 engine. At each stage—subsonic, sonic, and hypersonic—the car must stay aerodynamically neutral, neither lifting off nor hunkering down.



IMAGINE THE WIND: Computer modeling allowed designers to do without destructive testing at each critical speed, such as the sound barrier. This sonic boom can be seen forming at the nose [first and second images]. At an appropriate airspeed, panels deploy to add braking force [third and fourth images].

TOP: FLOCK LONDON; BOTTOM: THIRD IMAGE, BLOODHOUND PROJECT; ALL OTHERS, SWANSEA UNIVERSITY

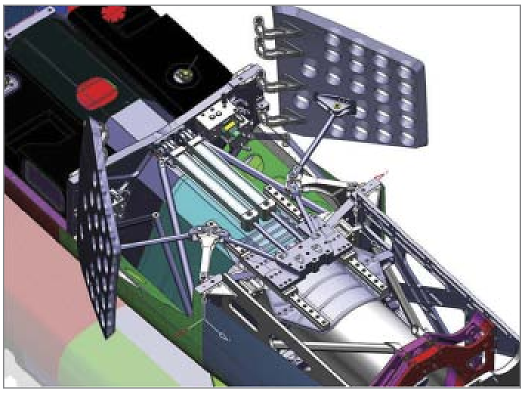


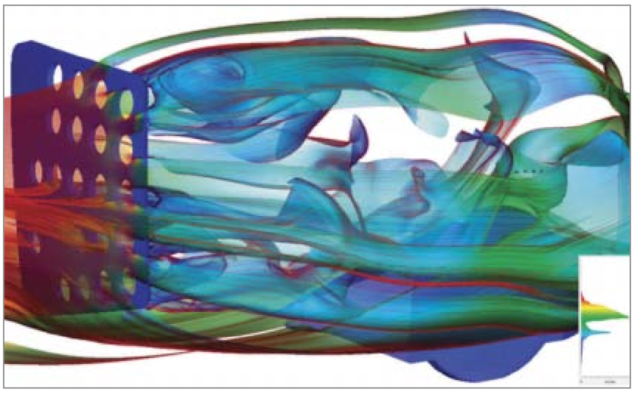
land-speed records, this team has used a combination of computer simulations and sensor data to test whether their designs are robust enough to cope. Thrust SSC pioneered this technique in the 1990s, but to a much smaller extent: Wind-tunnel and rocket-sled tests on models supported certain computer simulations, and the car was equipped with sensors, but far fewer than Bloodhound will carry.

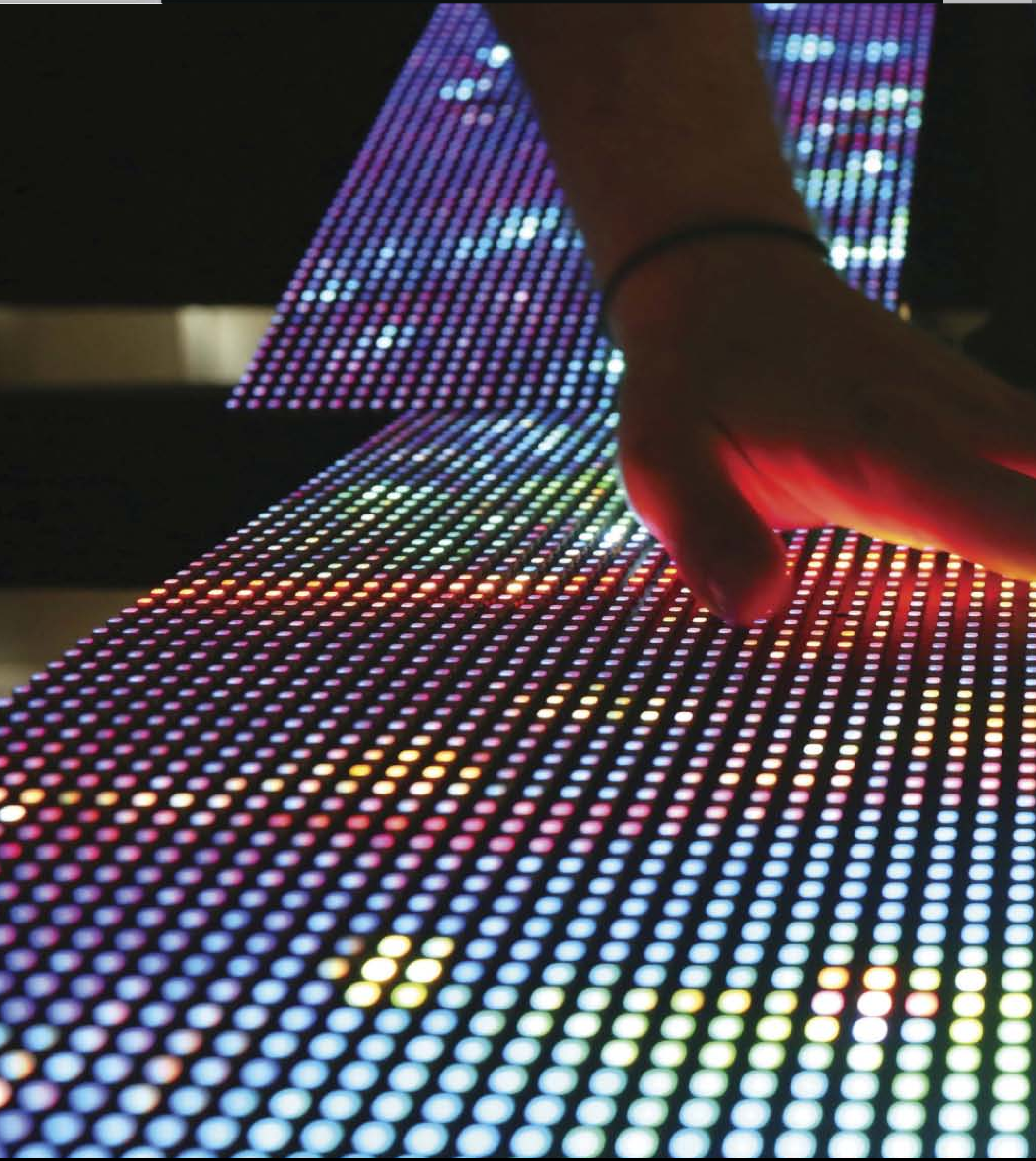
Take the wheels, for example. They will be the fastest-turning wheels in the world. And when the car is traveling at 1,600 km/h, material on the rim of a wheel will experience about 50,000 *g*'s. The wheels, which measure just under a meter across, are made of solid metal and are machined so that the rim is a shallow V shape that digs into the desert floor.

Initially, the team thought the wheels would have to be made from titanium, but a finite-element analysis (which simulates the stresses that solid structures experience) indicated that suitably forged aluminum would be strong enough. So Bloodhound's designers settled on an aerospace-grade alloy of aluminum with a light salting of zinc, copper, and manganese.

Not entirely trusting computer models for this vital component, they engineered two series of tests to confirm that aluminum wheels would work. In the | CONTINUED ON PAGE 50



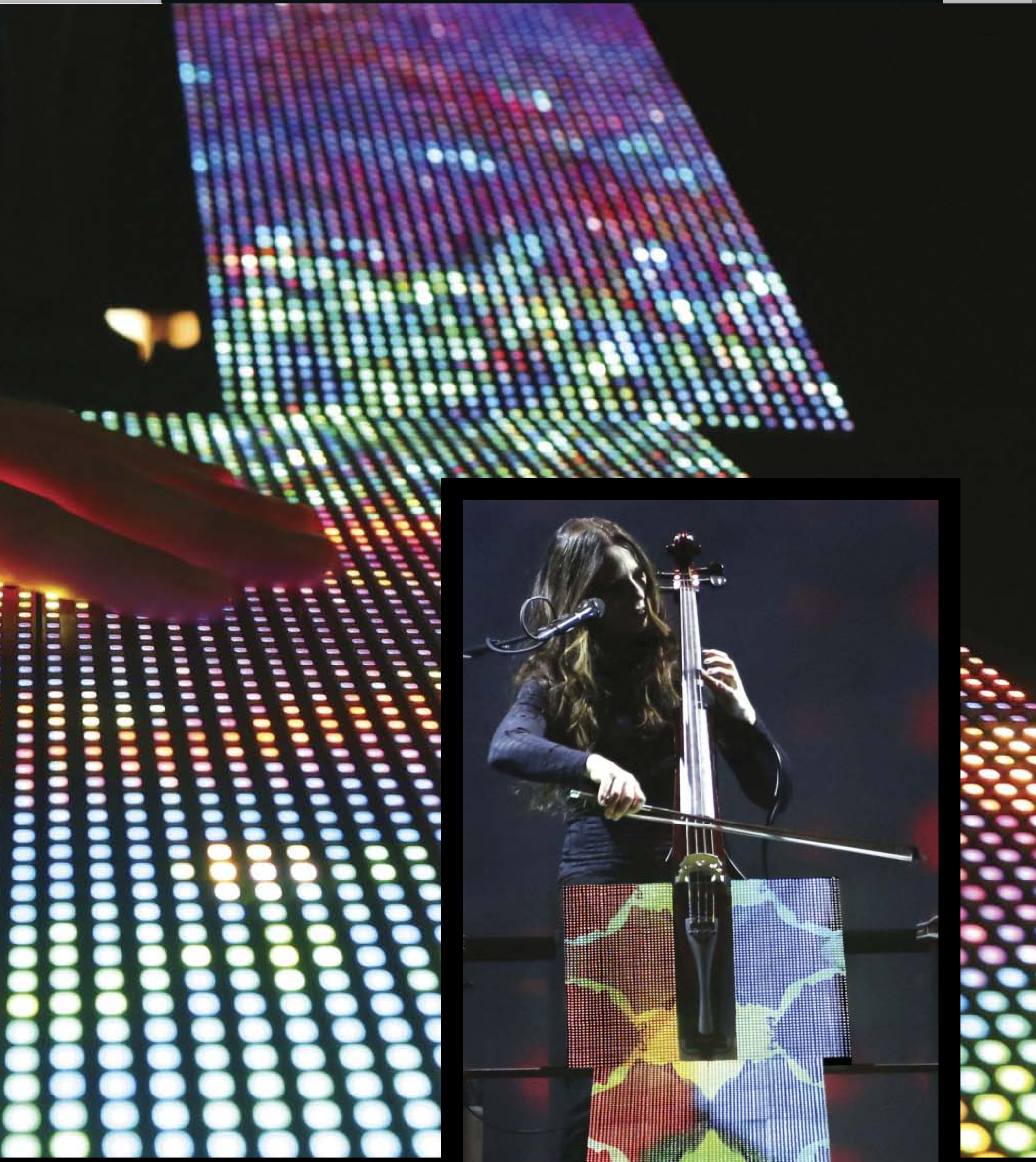


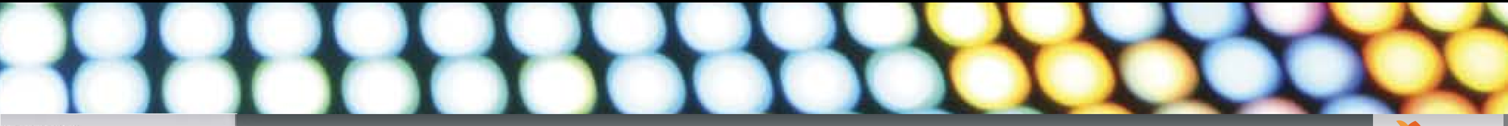


The Illuminated Cello

How visual artist Erika Harrsch engineered a brilliant new instrument for the 21st century

BY JEAN KUMAGAI





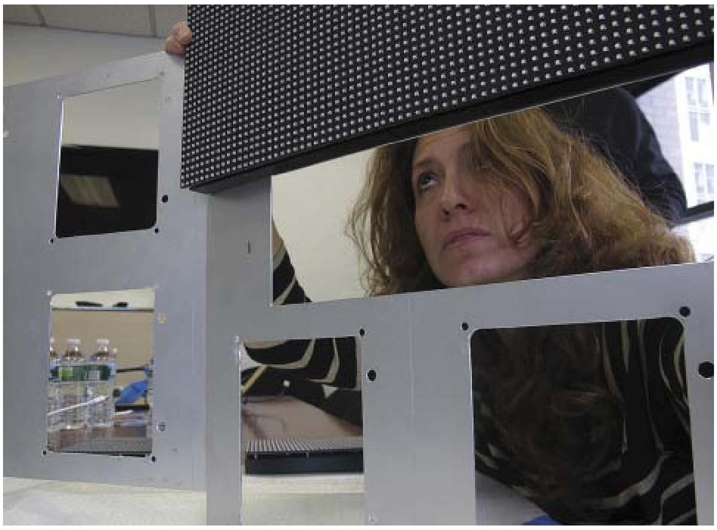
IT'S A WARM SUMMER evening in New York City, and the visual artist Erika Harrsch is having dinner with Meric Adriansen, an engineer and managing partner of the lighting design company D3 LED. Adriansen's company specializes in sophisticated LED installations for advertising and public art. After dinner, the two stroll through Times Square, where Adriansen points out a few of his company's immense, shimmering creations and describes how the visuals are programmed.

"We should do something together one day," Adriansen tells Harrsch. And just like that, a collaboration is born.

"For me, it was like an open window of possibility," Harrsch recalls of that evening three years ago. She soon knew exactly what she wanted to do: build a cello illuminated with light-emitting diodes.

Harrsch had recently begun working with the avant-garde composer Paola Prestini and cellist Maya Beiser on a new concerto. Until her dinner with Adriansen, Harrsch had been envisioning video backdrops against which Beiser would perform; she'd created similar works for other musical performances.

"This time, I wanted not just videos as background but as an integral part of the piece," Harrsch says. "I wanted to create a living sculpture, of music and light." And so she did: the LED cello. ■



HARRSCH FACED A NUMBER OF CHALLENGES: The cello had to be comfortable to play, the visuals had to make sense to the audience and also blend seamlessly with the music, and of course, everything had to work technically. To investigate the cello's ergonomics, Harrsch created a cardboard version of it, which Beiser experimented with [above] to see if the size and shape worked. They did.

The cello's "display" consists of eight 32- by 32-pixel LED panels arranged in a blocky "U" shape on the front of the instrument. Two panels sit on each side of the cello's bridge, and the remaining four panels form a square at the bottom. Worried that the display would look flat and rigid, Harrsch tilted the bottom panels to give the optical illusion of curvature.

The Yamaha electric cello [opposite page, top left] that Harrsch used as the base for her instrument is about the same size as its acoustic counterpart, but instead of having a resonant sound box, it amplifies the sound electronically. Would having LEDs so close to the instrument's delicate electronics create distortion? Harrsch contacted Yamaha seeking advice.

"They told us it was impossible," she recalls, "that what we were wanting to do would destroy the sound."

ALL PHOTOS: ERIKA HARRSCH

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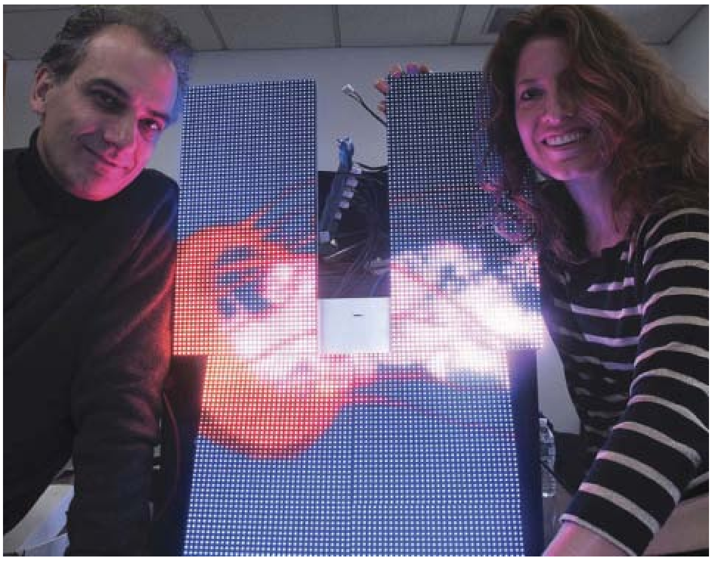

A BIT SHAKEN by Yamaha's admonition that her project was "impossible," Harrsch nevertheless continued to work with Adriansen [left, with Harrsch] and others to ensure that the LED panels would *not* interfere with the cello's sound. With engineer Dragoslav Scepanovic, whose machine shop isn't far from Harrsch's studio in Long Island City, N.Y., she designed an aluminum frame to hold the panels in place [opposite page, far left].

At the back of the cello—officially known as the Erika Harrsch/LED Cello—the panels are connected by Ethernet cable to a motherboard. A laptop running software from Adriansen's company controls the LED panels' output. It's exactly the same software that runs the billboards in Times Square, Harrsch says.

That Times Square heritage wasn't exactly a selling point with composer Prestini [top, left] and cellist Beiser. "I was quite skeptical about the LED in the beginning," Beiser recalls. "I was worried about just the warmth of it."

But Harrsch showed them how the LEDs could be programmed to create effects that were lush, vibrant, and nuanced. To keep the lights from appearing too harsh, she dialed back the brightness to about 30 percent. Video designer Brad Peterson [above, standing] worked with Harrsch on the videos that would be projected through the cello.

THE LED CELLO debuted in February 2014 at the Krannert Center for the Performing Arts, in Urbana, Ill., in a concerto called *Room No. 35*, written by Prestini. The work is based on a novella by Anaïs Nin that traces a woman's path of self-discovery. Room 35, Prestini explains, "is one of the rooms that one of her selves goes in, to discover a deeper world within her."

In the months leading up to the performance, Beiser, Harrsch, and Prestini [right] worked closely with members of the eDream Institute, a research and education center at the University of Illinois that's devoted to the digital arts and technology. Shown above with Harrsch are, from left, graduate students Kyungho Lee and Michael Junokas and **Guy Garnett**, the institute's associate director.

AS THE CONCERTO OPENS, Beiser is seated center stage, playing an acoustic cello. But around minute 21, she sets her instrument aside, slowly climbs a set of stairs to an elevated platform, and takes up the LED cello. The first few notes sound hesitant and experimental.

"I'm just kind of improvising different sounds," Beiser says. Images flash and pulse on the cello's face, and as the music intensifies, so do the visuals, radiating onto the screen behind. In the piece's final moments, the LEDs blaze a bright white for a split second and then go dark. "It's very rock and roll," says Beiser.

This past April, Prestini's company, Via Records, released the official DVD and CD of the concerto, along with a companion work called *House of Solitude*. Although there are no firm plans to stage *Room No. 35* again, Prestini doesn't rule it out.

In the meantime, Harrsch is working with Adriansen on an updated version of the instrument—call it LED Cello 2.0—that will incorporate lighter-weight panels with a denser pixel count and smaller LEDs. The new cello's visuals will be programmed to respond to the music and the musician's movements. Harrsch knows it won't be easy.

"Sometimes I wish I could stop the creative entity that resides inside me," she says, laughing. "Because it takes me wherever my most bizarre dreams are. And sometimes it takes me to places that are very difficult to get out of."

WATCH THE TRAILER AND POST YOUR COMMENTS AT HTTP://SPECTRUM.IEEE.ORG/LEDCELLO-0815

HOW TO COMPUTE WITH DATA YOU CAN'T SEE

Web applications could increase security by keeping data encrypted even during computations

By Raluca Ada Popa & Nickolai Zeldovich

Not long ago, hackers stole about 40 million debit- and credit-card records from Target, another 56 million records from Home Depot, and nearly 5 million patient records from hospital operator Community Health Systems. And this past June, personal information about millions of federal employees was taken from the U.S. Office of Personnel Management. These are just a few thunderclaps in the perfect storm of cyberattacks and data breaches making headlines recently.

Despite massive efforts to guard sensitive data, hackers often manage to steal it anyway. It's a problem that's becoming especially acute, now that huge amounts of information are being concentrated on the servers of various cloud service providers. Most times we don't even know where these machines are located; how can we possibly feel that our data is safe with them?

Here's one way: Encrypt the data before it's stored. That way, even if attackers manage to break into the cloud provider's system and steal data, they'll just get meaningless gibberish.

This might seem a simple solution, but it has a big shortcoming: When data is encrypted, it's useless to the bad guys, for sure. But in many instances encryption makes it useless to the good guys as well.

Today's cloud providers typically perform many different kinds of useful computations on the data you entrust them with—looking things up, compiling statistics, analyzing trends, and so forth. Some apply very sophisticated machine-learning techniques to your data. But no one can do any of that if the data is encrypted.

How, after all, could Facebook possibly run a face-detection algorithm on your photos to recognize your friends if the images it holds are scrambled? And how could Amazon offer recommendations if it can't make sense of the purchase history it keeps on you?

So it would seem foolhardy to pursue encryption for anything other than perhaps simple data storage. In the past few years, however, a technique has emerged that achieves the seemingly impossible: It enables a cloud provider to perform many kinds of computations on data that has been encrypted.

The technique relies on special mathematical properties of certain encryption schemes that allow the cloud provider to carry out useful computations and produce an encrypted result. The end user can then decrypt that result to get the answer he or she is looking for.

The beauty of this approach is that the data stored by the cloud provider is always encrypted.

So even if someone steals every last bit of data from a cloud service's machines (or subpoenas the information on them), he gets only the encrypted data, which is essentially worthless. Indeed, this approach also protects you from the possibility of a hacker obtaining complete access to the cloud provider's computers and running the software on them at will. Even that intrusion won't reveal your data.

Today's work on computing with encrypted data has deep roots, reaching back almost four decades. But such computations are only now becoming practical, thanks in part to software tools we helped develop at the MIT Computer Science and Artificial Intelligence Laboratory. Those tools are complicated, but you don't need to understand their mathematical intricacies to get a general sense of how they work and how, contrary to intuition, you can compute useful things with data that you can't even see.

To make clear what we've been working on, consider a hypothetical example. Imagine that someone—we'll call her Alice—uses a medical Web application that runs in the cloud. She uses her browser to enter various kinds of sensitive information—disease symptoms, physical activity, diet, credit-card information for payments, and so forth—on the provider's website. But the company running this service is scrupulous about security. It has arranged things so that Alice's personal information gets encrypted on her local machine and is then sent to the cloud provider, so that the provider receives and stores only encrypted data.

Later, Alice asks for certain things to be computed based on what she had entered earlier—fitness level, diet recommendations, whatever. Remarkably enough, the cloud service can carry out these computations using just Alice's encrypted data. The answers will not seem to make any sense to the provider, but software running on Alice's machine automatically decrypts these results and presents them in Alice's browser in the usual way. So from her standpoint, the interaction with the Web application appears perfectly ordinary.

Let's imagine also that a doctor who is authorized to access the service asks for statistics about how many patients were sick in a given week, what the risk factors were for people who contracted a certain disease, or some other information. This doctor, too, gets results that are computed with encrypted data and returned to her machine in an encrypted form, at which point they are automatically decrypted and displayed.

In all, Alice and the doctor enjoy the same level of service they would have experienced with a regular Web application. The difference is that sensitive information is never exposed to hackers who might try to break into the provider's database or listen in on network communications.

How can this possibly work? For concreteness, let's consider a very simple computation. Imagine that the doctor wants to know the total number of people using the system who suffered from a specific disease during the past year. Assume that the cloud service has records of the number of people who reported this disease in each month of the year, but it holds that information in encrypted form.

To answer the doctor's query, the cloud provider needs to somehow add up 12 different encrypted numbers and return the result. That might seem impossible, but it can be done if the encryption scheme is chosen properly.

Conveniently, in 1999, while working on his thesis at École Nationale Supérieure des Télécommunications of Paris, Pascal Paillier developed an encryption system with a fantastic property: If you multiply a set of numbers after they've been encrypted, you will obtain, remarkably enough, the encrypted version of their sum.

So the cloud service in our example just needs to use Paillier's encryption system and multiply together the 12 encrypted values corresponding to the disease totals for each month of the year. This operation will generate

RT2AR
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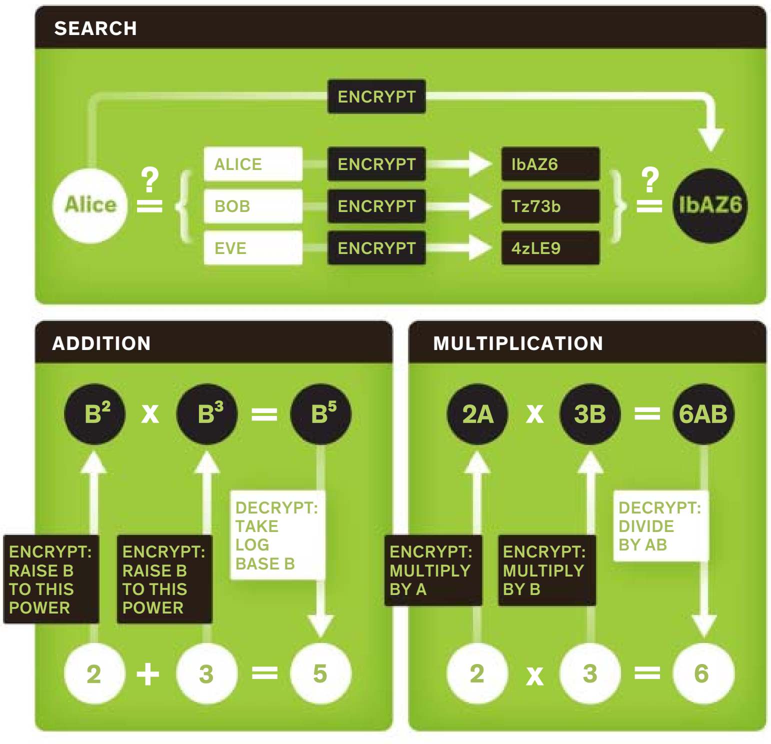
TOP 10 CORPORATE HACKS

THESE MASSIVE BREACHES go back more than a decade. An AOL employee stole 92 million records in 2004. The most recent victim here was Anthem, this past February.

Source: Information Is Beautiful (http://www.informationisbeautiful.net)

Company [industry]	Number of records stolen
eBay [e-commerce]	**145,000,000**
Heartland [financial]	**130,000,000**
T.J. Maxx / T.K. Maxx [retail]	**94,000,000**
AOL [Web]	**92,000,000**
Anthem [health care]	**80,000,000**
Sony [gaming]	**77,000,000**
JPMorgan Chase [financial]	**76,000,000**
Target [retail]	**70,000,000**
Home Depot [retail]	**56,000,000**
Evernote [Web]	**50,000,000**

MULTIPLE ENCRYPTION SCHEMES



FOR SIMPLE SEARCHING [top], any encryption scheme will work, but for other operations you need to choose an appropriate method. To perform addition, for example, you could use exponentiation to encrypt the data, multiply the results, and compute the logarithm to decrypt [left]. For multiplication, you could first multiply by some chosen constants to encrypt the two numbers, multiply the encrypted values, and then divide by the product of the constants to decrypt the result [right]. These simple encryption schemes would not, of course, be sufficiently secure to use in practice, but they show the general strategy.

a value that is the encryption of the sum of those monthly tallies, without the service ever having access to the individual values. The cloud service returns this result to the doctor's machine, which decrypts the value and displays the total for the year on her computer screen.

This general approach to working with encrypted data isn't limited to simple addition. There are all kinds of other things you can do with encrypted data if you pick the right encryption scheme, including comparison, sorting, multiplication and other arithmetic operations, as well as trigonometric functions.

INFOGRAPHIC BY Carl De Torres

The idea of computing with encrypted data arose first in 1978, when Ronald Rivest, Len Adleman, and Michael Dertouzos wrote a seminal article titled "On Data Banks and Privacy Homomorphisms." In it, they introduced the idea of keeping data encrypted while computing things with it. They called an encryption scheme that could support such computation "homomorphic." They did not know at the time how to carry out an encryption that would allow all sorts of computations to be performed–and neither did anybody else–but they and other computer scientists were eager to find a way.

The quest lasted for more than 30 years. In 2009, Craig Gentry, then a graduate student at Stanford University, made a major breakthrough: He came up with an encryption scheme that allows a computer to calculate any function at all on data after it has been encrypted. Such a scheme is called fully homomorphic encryption.

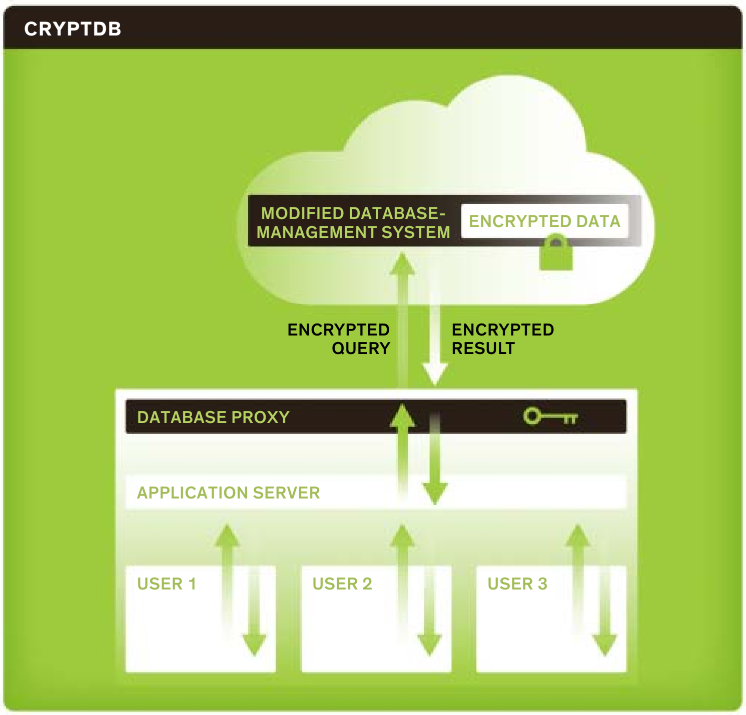
From a mathematical standpoint, Gentry's solution to the problem was truly beautiful. And soon, other researchers proposed additional fully homomorphic encryption systems aimed primarily at improving the performance and security of Gentry's original scheme.

Despite this progress, a huge problem remained: The best fully homomorphic encryption schemes took more than a million times as long to complete as the corresponding unencrypted computations. If it normally took a second for a website to compute your results, with fully homomorphic encryption you'd have to wait about 12 days. Such sluggishness was clearly a showstopper.

Then in 2011 a team of security and cryptography experts, which included the two of us, built a system called CryptDB. It allowed a Web application to perform a range of database queries in the widely used Structured Query Language (SQL) with only a 27 percent performance slowdown.

What was the trick? The key was to get away from the idea that one encryp-

SAFETY AT ALTITUDE



SECURITY IS OFTEN a concern when information is held in a cloud database. CryptDB addresses this issue by encrypting the data in a way that still allows normal database queries to be performed. The application itself runs locally, as does a database proxy, which performs the encryption and decryption. The proxy also translates queries into a form that can be run on the modified database-management system running in the cloud.

tion system would work for everything. Fully homomorphic encryption aims to support all functions within a single encryption scheme. That makes it slow even for simple operations.

We and our colleagues realized that an encryption scheme specialized for just one operation on the encrypted data could be much faster. Paillier's encryption scheme, for example, can compute the sum of encrypted values very quickly, but it can't compute anything else.

To support a variety of operations, then, you need to use a variety of specialized encryption schemes. Each is efficient at just one thing, but together they cover quite a lot of territory.

Currently, there are specialized (and fast) algorithms for many common operations, some of which we developed: addition, multiplication, comparison by equality or by order, set intersection, polynomial computation, machine-learning classification tasks, searching encrypted text, and others. Using all of them to encrypt your data, and therefore storing multiple sets of encrypted data, allows you to perform a variety of different computations with the encrypted results. You just switch back and forth among the encrypted data sets, in each instance using the one that corresponds to the operation you need done.

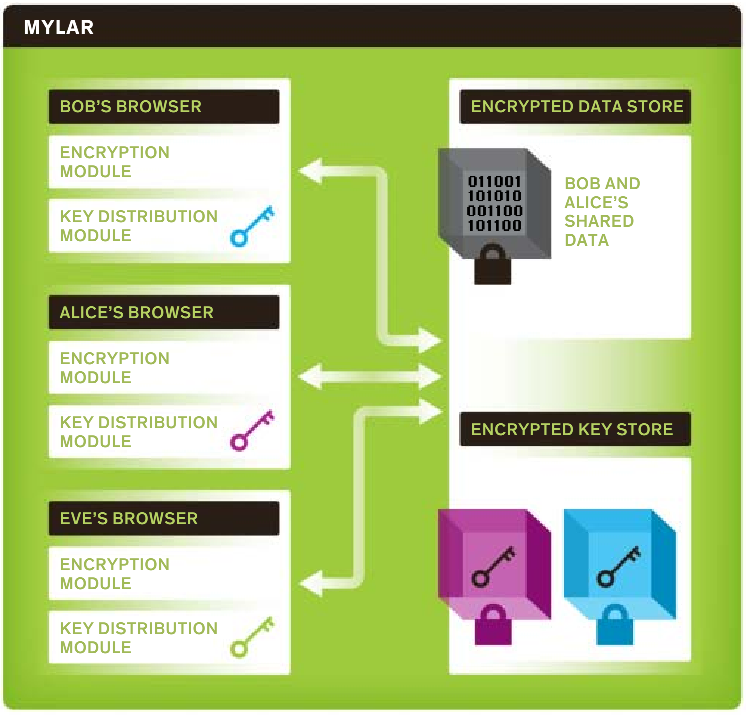
CryptDB exploited this insight for the first time in a practical way. As a result, it has gained traction in industry. For example, following CryptDB's lead (and giving credit to it), Google recently deployed a system called Encrypted BigQuery. It can perform queries on an encrypted version of Google's BigQuery database. And the software giant SAP implemented a system called Search Over Encrypted Data, which uses CryptDB on top of SAP's High-Performance Analytic Appliance database server. Also, researchers at MIT's Lincoln Laboratory use CryptDB for a special version of the open-source Apache Accumulo database.

Because each of these systems uses a variety of different encryption schemes, application designers are limited in how they can combine different operations. Still, being able to do SQL queries on a collection of encrypted data is often all you need.

Last year, we developed a system called Mylar to add to the capabilities of CryptDB. Mylar goes beyond just querying a database full of encrypted data—it enables users of a Web application to also share data with one another. Such data sharing is a staple of many Web applications: Facebook users share photos and posts with one another, users of an online calendar share events, and so forth. Mylar enables all such sharing, according to whatever permissions the user grants others.

INFOGRAPHICS BY Carl De Torres

SHARING WHILE CARING



THE AUTHORS' MYLAR Web-application framework allows users to share data with those they choose. This is done by encrypting shared data with particular encryption keys and then storing encrypted versions of those keys in such a way that only the proper users can access them. Here Bob and Alice use their keys [blue, purple] to obtain copies of a third key [black], which they each can use to access their shared encrypted data.

For instance, let's say Alice of our hypothetical example wants to share her medical history with her doctor so that she can be treated. The desire here is that both Alice and her doctor be able to decrypt Alice's medical information. A hacker, whom we'll call Malice, shouldn't be able to decrypt Alice's data, even if Malice manages to hack the cloud-service provider and steal all the data and code stored there.

The same should apply, of course, to any number of people who've chosen to share their information with this doctor—perhaps it's everyone in the database. Indeed, allowing a doctor access to everyone's data would be a prerequisite for answering many important questions. For instance, the doctor might want to search all the data stored on the cloud medical application to look for people with a rare disease. The search request she sends to the Web application would contain an encrypted keyword corresponding to the name of that disease. CryptDB could handle that request if all the data were encrypted with the same cryptographic key. The problem, of course, is that different people's records will inevitably be encrypted with different keys, so searching through the whole set is normally impossible.

Mylar skirts the problem by distributing a shared encryption key to users who want to share data. That must be done carefully, to prevent a hacker from tricking users into sharing data with a server he controls.

To avoid that, Mylar includes a special browser extension that verifies the code downloaded from the server. The system still works without it, but less securely. Mylar also offers an identity-provider service, which acts like a Web certificate authority. (A Web certificate authority is an entity that helps ensure that you are connecting with the real thing when you visit a website using https, the secure version of hypertext transfer protocol.)

We have used Mylar to secure a variety of Web applications—for health care, chats, forums, photo sharing, calendars, and online courses. These experiments showed that Mylar is fast: It increases computation time by only 17 percent on average.

Mylar has also been adopted in a real-world application, one used at the Newton-Wellesley Hospital, in Newton, Mass., to collect information about women with endometriosis, a painful abdominal disorder. At this very moment, Mylar is helping to protect the privacy of these patients.

We are confident that computing with encrypted data, using systems like CryptDB and Mylar, will become one of the primary strategies for protecting confidential information stored in the cloud. And this approach can protect more than just data: It's also been used to secure cloud computers running linear algebraic operations, big-data analytics, and machine-learning tools.

The security of information stored online is a huge problem these days, and computing on encrypted data could be an important part of the solution. It protects sensitive information against theft for the simple reason that if even the company holding the data has no idea what the values mean, an attacker will have nothing of value to steal. ■

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BIG GRID: Electricians work on a 1,680-kilometer-long high-voltage DC transmission line that will move power from China's Xiluodu hydroelectric plant to Zhejiang province.

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GUTTER CREDIT GOES HERE

A GLOBE-SPANNING supergrid

With a little DC wizardry and a lot of cash, we could swap power across continents

By Clark W. Gellings

REPORTS ABOUND OF HOMEOWNERS and businesses unplugging from the power grid and opting instead to generate and store their own electricity. Such grid defections may make sense in places where electricity rates are sky-high or service is spotty. But for just about everywhere else, it's far more sensible to do the very opposite: interconnect regional electricity networks to form a globe-spanning supergrid. • What makes this idea so compelling are the major strains on today's power grids: soaring energy demand in fast-growing megacities; rapid expansion of carbon-free but intermittent wind and solar power; and the ever-increasing need to secure grids against electronic and physical attacks. The smaller and more isolated a power network is, the more difficult it is to maintain the nearly instantaneous balance between electricity supply and demand.

FRENCH CONNECTION: A recently completed HVDC link between France and Spain doubles the amount of electricity that can be exchanged between the two countries. Converter stations like the one shown here sit at each end of the line, converting high-voltage AC to DC and DC back to AC.

But the technology now exists to transmit massive amounts of electricity over long distances without significant losses, thereby allowing operators to balance consumption and generation across an entire continent–or, potentially, the globe. If an outage occurs in one country, the sudden change in line voltage and frequency could trigger a generator thousands of kilometers away to compensate for the shortfall. Similarly, if the wind in a normally wind-dependent area dies, electricity from its neighbors could quickly fill in. Or if one region is experiencing heavy rainfall, hydroelectric dams there could capture the energy, to send elsewhere as needed. A supergrid would ensure that all or nearly all the electricity that's generated would get consumed, thus avoiding such wasteful practices as paying wind-farm operators to curtail production or dumping energy that's not immediately needed. (To be sure, storing excess energy would also help avoid such problems, but large-scale economical energy storage is still not widely available.)

In general, a global supergrid would allow power to be generated far from population centers. For instance, some of the world's best sunlight can be found in the sparsely populated region south of Darwin, Australia, where it's estimated that all of that country's energy needs could be supplied from a solar farm the size of a cattle station. With an undersea link to Southeast Asia, that electricity could also be dispatched to countries like Indonesia, Papua New Guinea, and Singapore. And with a supergrid in place, operators could significantly scale back their spinning reserves–backup capacity that they can tap if demand spikes but in practice is rarely used.

So what would it take to build a global supergrid? Technologically, it would hinge on a globe-encircling network of high-voltage direct-current (HVDC) transmission systems, most of the components of which already exist. Beyond that, regional grid operators would need to agree on how to pay for such a network, establish rules for trading the electricity, and specify the technical codes and standards that will allow the supergrid to operate safely, reliably, and securely.

THE ROOTS OF THE GLOBAL SUPERGRID stretch back to the dawn of the power industry, when the "war of the currents" raged between the era's two great inventors: Thomas Edison and Nikola Tesla. In 1882, Edison demonstrated the first commercial electric power plant, which was based on direct current. But it was Tesla's alternating current that would rule the day.

In 1895 Tesla's dream of generating electricity from Niagara Falls was realized, and within a few years that energy was electrifying New York City, 700 kilometers away, thereby proving the superiority of the AC system. Well into the 20th century, the world's power systems were based on AC.

PREVIOUS PAGES: XU YU/XINHUA/CORBIS; THIS PAGE: SIEMENS

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The key to AC's triumph was that power could be transformed to higher voltages by use of magnetic induction and then sent over long distances at low currents, minimizing the losses due to resistance; at the destination, the system would reduce the voltage for local distribution. At the time, there was no way to do the same with DC. But power engineers also knew that a DC system operating at high voltage would be superior to AC for the same task, because the amount of electricity lost during DC transmission would be far less than with AC.

How much less? Let's say you're transmitting a given amount of power by high-voltage DC: When you double the voltage, you need only half the current of a comparable AC system, thus reducing your line losses by a factor of four. You also need a lot less wire, because DC current penetrates the entire conductor of a power line, whereas AC current remains largely near the surface. Put another way, for the same conductor size, the effective resistance is greater with AC, and more power is lost as heat. In practice, that means the overall transmission infrastructure for AC far exceeds that for DC. To transmit 6,000 megawatts using a 765-kilovolt AC system, for instance, you'd need three separate single-circuit transmission lines, which would cut a right-of-way path about 180 meters wide. Compare that with an 800-kV DC system, which would require just one 80-meter-wide path.

HVDC also allows for the easy transfer of power between grids that are operating at different frequencies. The converters, cables, breakers, and other components for HVDC are more expensive than those for AC, so it only makes economic sense to use HVDC over distances of 500 km or more. But that break-even distance has continued to come down as the cost of DC components drops.

With these advantages in mind, power engineers experimented with DC transmission technology throughout the 20th century. The key building block for HVDC was and still is the converter, located at either end of an HVDC line. It serves to convert high-voltage AC to high-voltage DC and DC back to AC. Through the 1960s, such converters relied on mercury-arc valves, which were basically electronic switches that could only be turned on and not off, thereby limiting their functionality and resulting in substantial losses.

In the 1970s came the next advance in DC technology: water-cooled thyristors, a type of giant solid-state switch that can be turned on and off. The first ones were demonstrated in 1978 at the Nelson River HVDC Transmission System, which sent power from hydroelectricity stations in northern Manitoba, Canada, to the country's populated south.

Since then, HVDC has spread only modestly in North America, but it has taken off in other parts of the world, most notably Brazil, China, India, and Western Europe. Starting in the late 1990s, these newer HVDC deployments have relied on insulated gate bipolar transistors (IGBTs), which are specialized transistors that can be switched many times per cycle. In the latest IGBTs, the gates can open or close in less than a billionth of a second.

Today's HVDC converters are known as voltage-source converters (VSCs). Although traditional converters continue to be used for higher-voltage, higher-capacity transmission, VSCs make it easier to integrate HVDC lines into existing networks. The VSC concept was first demonstrated in March 1997 between Hellsjön and Grängesberg, Sweden, at a modest 3 MW and 10 kV. Five years later came the first sizable VSC installation: the Cross-Sound Cable project in Long Island Sound, between New York and Connecticut. That project had a moderately high rating of 330 MW, but conversion losses were also high, at 2.5 percent. With the latest VSCs such losses have been cut to just 1 percent.

What's more, it's now possible to have multiple terminals along a single HVDC line, so that you can tap into the line at intermediate points, rather than just at the end. By moving beyond point-to-point HVDC transmission, you'll be able to connect the lines into a mesh, which of course will be more complicated to control but potentially more robust.

WHAT OTHER TECHNOLOGIES will the global supergrid need? One immediate need is fast-reacting, large-capacity circuit breakers that can handle short-circuit currents above 60 kiloamperes and respond to detected faults within milliseconds. Three years ago, the Swiss company ABB announced a hybrid electromechanical breaker that gets part of the way there. Earlier this year, Siemens announced that it had successfully tested 5-kA breakers for China's Xiluodu-Jinhua HVDC line, which runs from Sichuan province to Zhejiang province. Alstom has also reported a circuit breaker prototype in this range. But much more work is needed to bring down the cost and size of these devices and boost their performance.

In the longer term, power cables made from high-temperature superconducting materials instead of copper or aluminum would greatly accelerate the deployment of the global supergrid because they can handle substantially higher power with essentially zero losses. Although they do need to be cooled to liquid-nitrogen temperatures—below 77 kelvins—the losses from refrigeration and other sources are less than half those of conventional AC and DC overhead transmission lines. And superconducting DC cable requires even smaller rights-of-way than does HVDC with traditional cables. Several projects have demonstrated superconducting cables over short distances, such as the recently installed 500-meter, 80-kV DC line on the Korean island of Jeju. At present, though, they're still considerably more expensive than conventional cable.

Another promising area involves advanced power electronics made from materials other than silicon. Silicon's abundance, low cost, simple processing, and room-temperature operation have made it the material of choice for power and other semiconductor devices, but research on novel materials such as silicon carbide and gallium nitride has shown real promise for the kind of power switching required in HVDC networks. These wide bandgap semiconductors can operate at higher temperatures than standard silicon devices do, and they support higher currents and higher voltages with less resistance. If they can be made commercially viable, wide bandgap devices would both reduce the cost and increase the functionality of HVDC converters.

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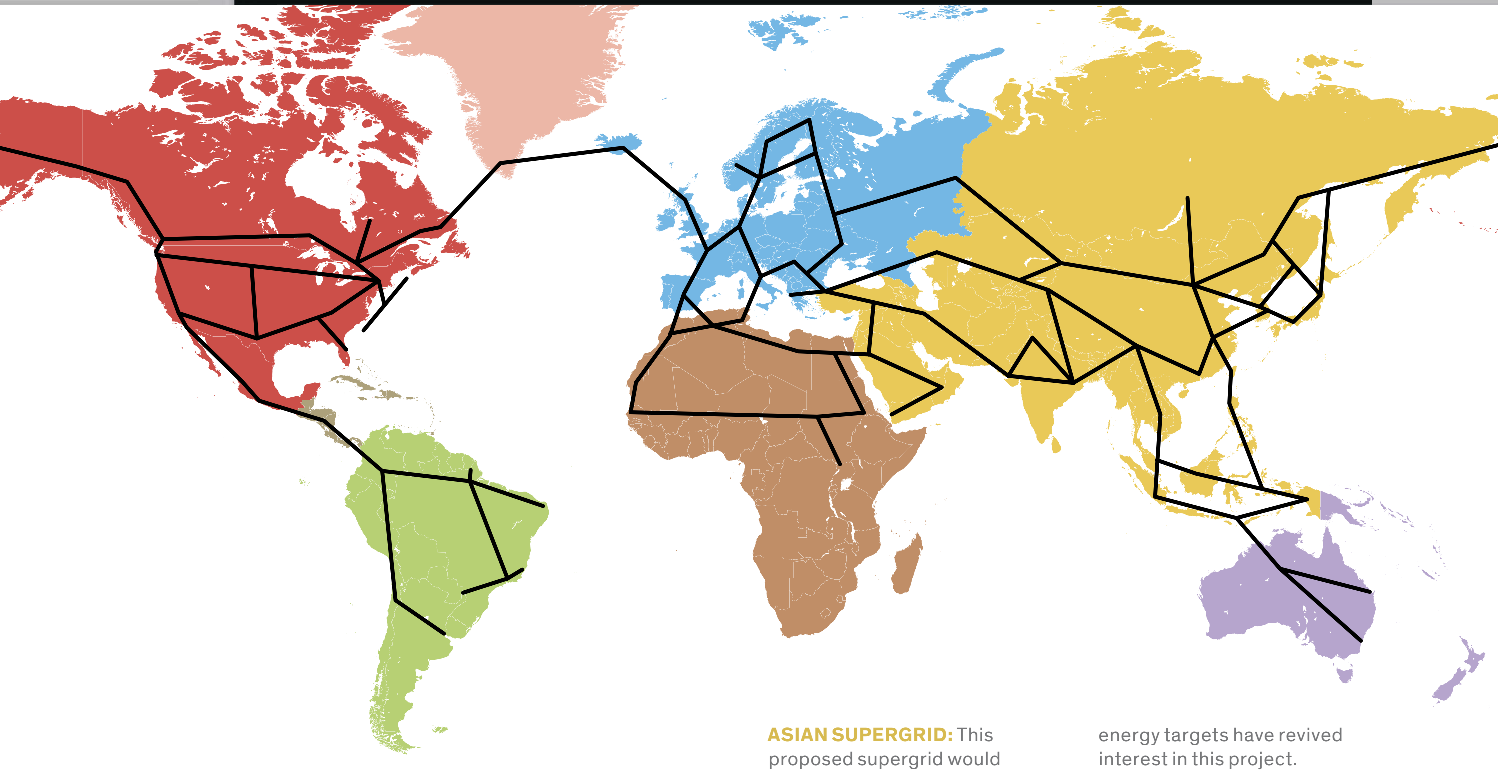

First Steps to a Global Supergrid

DESERTEC: First proposed by a German-led consortium in 2009, this project aims to harvest solar power in the Mediterranean and other deserts of the world and use HVDC to transmit the electricity to population centers.

MEDGRID: Similar to Desertec, this supergrid plan calls for developing 20 gigawatts of solar power generation in North Africa, of which 5 GW would be exported to Europe. The Medgrid electricity network would become the backbone of the European supergrid.

CHINA'S SUPERGRID: To deliver solar and wind resources from the north and hydropower from the south to cities in the southeast, China has installed the most extensive network of high-voltage AC and HVDC in the world. It's now expanding its transmission grid with 13 to 20 new HVDC lines.

GOBITEC: Also modeled on Desertec, this project would develop wind and solar photovoltaic systems in the Gobi Desert and deliver that power using an HVDC grid that would connect Irkutsk, Russia, in the north, with Shanghai and Seoul in the south and Tokyo in the east.

SOUTHEAST ASIAN SUPERGRID: This grid is envisioned as an undersea HVDC cable running from the northern coast of Australia along the Indonesian archipelago and up into the Philippines, Malaysia, and Indochina and then eventually into China, with the aim of exporting northern Australia's abundant solar resources to Southeast Asia.

ASIAN SUPERGRID: This proposed supergrid would establish links between the electricity grids of China, Japan, Korea, Mongolia, and possibly Russia. An underpinning of the Asian supergrid is to enable free trade in electric power. Masayoshi Son, CEO of Japan's Softbank, is said to be a key proponent of this plan.

NORDIC GRID: By 2030 Northern Europe is expected to see a substantial increase in renewable generation from wind and hydropower. While many of these countries are already interconnected to each other, further grid development will be needed to export the surplus to the rest of Europe and perhaps Russia.

NORTH SEA OFFSHORE GRID: Similar to the Nordic grid, this would harvest wind power generated in the North and Baltic Seas while opening broader markets for those resources.

ICELINK: This is a recent incarnation of a 60-year-old idea to link Iceland's power system with that of Europe through Scotland. Increasingly high electricity prices in Europe and more ambitious renewable energy targets have revived interest in this project.

BRAZILIAN SUPERGRID: To make use of hydropower in the country's interior, Brazil is building a grid consisting of HVAC and 600-kilovolt HVDC, including the 2,385-kilometer-long Rio Madeira transmission link, the world's longest.

HYDROGEN-ELECTRIC ENERGY SUPERGRID: Envisioned as a continent-wide underground HVDC transmission network, this supergrid would rely on hydrogen-producing advanced nuclear reactors. The transmission line, made from superconducting cable, would carry electricity as well as hydrogen to cool the cable. The hydrogen would also provide daytime energy storage for leveling energy consumption peaks. Excess hydrogen could be sold in local electricity markets or for commercial use.

ATLANTIC WIND CONNECTION: This proposed offshore transmission line would span the mid-Atlantic region of the United States from New Jersey to Virginia to connect wind farms in federally designated wind energy areas.

IF YOU WERE TO BUILD A GLOBAL SUPERGRID, where would you start? One obvious place would be China, which is now the world leader in the development and deployment of grid technology, in particular HVDC. The country has begun to exploit its massive potential solar and wind resources in the north and substantial hydropower potential in the south. To deliver that approximately 1,300 gigawatts of generation to population and industrial centers in the east and south, China has already installed the most extensive network of high-voltage AC and HVDC in the world, and over the next five years it plans to build another 13 to 20 ultra HVDC lines (in the 800-kV and 1100-kV range). Those upgrades have not come cheap: In 2014 China spent US $65 billion on such projects, and it is expected to sustain that level of spending over at least the next five years. The International Energy Agency estimates that China will need to spend more than $4 trillion from now until 2040 to overhaul the way it transmits and distributes electricity. Liangzhong Yao, vice president of renewable energy and smart-grid technologies at the China Electric Power Research Institute, has reported that his group is also looking at the feasibility of an intercontinental transmission grid to connect China with Europe, the Middle East, and North Africa.

Another logical starting point for a global supergrid is Europe, where the European Commission has been calling for a pan-Europe supergrid since 2008. The planning for such a grid is being led by the European Network of Transmission System Operators for Electricity (ENTSO-E), which represents 41 transmission system operators in 34 European countries.

The general idea is to build an HVDC grid that would connect these European countries with neighboring regions, including Kazakhstan, North Africa, and Turkey. A study by Gregor Czish of Kassel University, in Germany, found that with such a grid in place, Europe's energy needs could be supplied largely by wind power, with only modest amounts of biomass generation as a supplement. An industry group called Friends of the Supergrid has been vocal in promoting the technology, regulation, and financing that would be needed to pull off such an ambitious plan.

To date, a number of key European HVDC interconnections have been completed or reached advanced stages of planning, including the €10 billion project to connect Germany's energy-rich north with its energy-starved south, two others to link Germany to Norway and Norway to Denmark, and a just-completed HVDC intertie between France and Spain.

To be sure, a global supergrid would require quite a bit more infrastructure: by my estimate, roughly 100,000 km of HVDC lines and 115 converter stations, based on planned projects and assuming redundancy in some areas. A few of these stations would be "superstations," such as the one envisioned by the developers of the Tres Amigas project in New Mexico. Tres Amigas is intended to connect North America's three primary grids (west, east, and Texas) and also provide some energy storage. The global grid will need something similar wherever large regional grids come together. (See "First Steps to a Global Supergrid" for a list of proposed supergrid projects in Asia, Europe, and other parts of the world.)

BY FAR THE GREATEST HURDLE facing the global supergrid is how to pay for it. It's hard to attach a firm number to such a vast and complicated undertaking, but proponents point out that its costs would be more than offset by its many advantages. In a 2013 paper in the journal *Renewable Energy*, Spyros Chatzivasileiadis, Damien Ernst, and Göran Andersson looked at previous studies of supergrids as well as completed projects to estimate what it would take to build an 800-kV, 3-GW undersea HVDC cable that's 5,500 km long—about the length you'd need to connect New York City with Oporto, Portugal. (At present, 800 kV is significantly beyond what's commercially available for submarine cables.) The authors concluded that the cable itself would cost from €1.15 million to €1.8 million per kilometer, and each terminal converter would cost about €300 million. Assuming thermal losses of 3 percent and a 40-year lifetime, among other things, the researchers estimated that transmitting electricity via such a cable would run between €0.0166 and €0.0251 (US $0.0189 and $0.0286) per delivered kilowatt-hour; the comparable figure for U.S. residential customers is about $0.011/kWh, which covers transmission but not power generation. The cost of the generated power with the HVDC supergrid would almost certainly be much lower than what's available today because operators would be able to buy electricity from the least expensive source.

For the countries of the world to organize and fund a global supergrid, a strong international consensus for renewable (and perhaps nuclear) energy will need to form. This could be accelerated if a worldwide agreement could be reached on taxing greenhouse-gas emissions so as to create a financial incentive for shifting to carbon-free energy. Government funding will likely be needed to support the first segments of the global supergrid, but once those are in place, a carbon tax would help catalyze private-sector funding.

Beyond just the financing, governments and grid operators will need to agree on the rules for free trade in electricity. Electricity trading through a wholesale market, perhaps broken up into regions, would enable the kind of efficient power flows a global supergrid would offer.

A major collaborative planning effort will also be needed to bring together the existing grids and the planned regional supergrids. As noted earlier, China and Europe are well along in planning their HVDC networks. But in the United States, for example, transmission planning remains largely a state-level exercise, in part because states control land use and regulate investor-owned utilities. Such technical and logistical decisions as where to locate the supergrid's points of connection, how to configure the HVDC grid, what voltages to use, and where and whether to use overhead or submarine systems will all need to be hammered out.

Last but certainly not least, all parties will need to agree on the technical specifications that will define the parameters of each transmission line, converter station, and generator so as to allow the global supergrid's safe, reliable, and stable operation.

So, yes, a global supergrid will cost a great deal and no doubt take many decades to put in place. But obvious precedents for such an undertaking already exist in the international transportation and telecommunications sectors. And the alternative—doing nothing and continuing to rely heavily on fossil fuels and inefficient, disconnected power grids—will cost even more. ■

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BUILDING BLOODHOUND

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first, the engineers put wheels onto a trailer carrying 3.5 metric tons of water to mimic the weight of the fully fueled car. The team then pulled the trailer across the desert where the record attempt will take place: Hakskeen Pan, in the northwestern corner of South Africa. Using a small truck as a tow vehicle, they were able to get the trailer going up to about 60 km/h–good enough for a low-speed test of the wheels' ability to bear weight.

The engineers also put the wheels into a rig that Rolls-Royce uses to test compressor discs for its jet engines. "Metal is a very uniform material, and it can be modeled quite well," says Holdsworth. "We were monitoring the stretch at the rim and the changes at the hub with a laser sensor rig, and the stretch that the [finite-element analysis] predicted matched up with what we saw, including the effects of the temperature rise from air friction."

That agreement between measurements and modeling gave Bloodhound's designers greater confidence in their computers, which they've used to design all of the structural features of the car, including its tail fin. "This is the hardest-working tail fin in history," says the engineering lead for mechanical design, Mark Elvin. "Not the fastest necessarily, but relative to a tail fin on a supersonic aircraft that flies at 45,000 feet, it's being pushed through treacle."

Elvin and his colleagues are using a combination of finite-element analysis and computational fluid dynamics (CFD), which models airflow and predicts the stresses it will create on the component. The results have given the team confidence that this aluminum tail fin can stay the course.

Bloodhound's entire structure–the titanium skin of the upper chassis, which is supported on aluminum ribs; the steel under chassis, designed to withstand a supersonic spray of desert gravel and sand; the carbon-fiber monocoque that surrounds the driver and forms the air intake for the EJ200–is perforated with hundreds of millimeter-wide holes. These tiny openings lead to pressure sensors fixed to the inner surface of the skin. Other sensors include a network of strain gauges placed at strategic points on the car's structure.

These sensors will, in all, collect 197 channels of data as Bloodhound runs, measuring the air pressure and the flex of the body as the car skims over the desert. "The pressure sensors are placed at zones of high transition, where the airflow changes direction," says Holdsworth. "The sensors we're using are designed for aerospace, so they're fine for pressures well above what we'll experience even at Mach 1.4, which is about 12 tons per square meter at the front of the car."

"We've even got pressure tappings inside the wheel wells, because trying to use CFD to model the airflow around a wheel spinning at 10,500 rpm–with air coming in from the front, with debris getting flung up by the wheel–is very, very difficult," Elvin adds. Yet it's critical that the engineers know what's going on. "We'll be checking that the pressure stays within the design limit, because if it doesn't, the arch will crack or burst, and all that air and debris will be flung rearwards," he says. To guard against such a calamity, Bloodhound is fitted with panels strong enough to withstand the impact of a fist-size fragment breaking off from a wheel.

Computers will download all this sensor data at the end of each run. The engineers will then compare the data with numerical simulations of the car running at the same speed to see if there are any discrepancies. "As long as we're close to what we expect, we know we'll be safe to increase the speed in the next run," says Elvin.

If the pressure sensors show greater-than-expected lift or downforce, for example, going faster could make the car take off or dig itself into the desert floor. To avoid this, the car's two sets of aerodynamic winglets can be repositioned. "We have the option to run them up or down by 5 degrees," Elvin explains. But they won't adjust automatically. Instead, the team will work out how the winglets should be positioned for a given speed, and the driver will dial in whatever is called for.

HAND IN GLOVE: The steering wheel was formed of hollow titanium to fit Andy Green's hands. It is light, yet tough enough to take wild handling should the planned straight-arrow course go awry.

STEFAN MARJORAM

THRUST SSC USED SIMILAR sensor systems, although to a much lesser extent than Bloodhound. "In the early days, the Swansea University team reran the Thrust SSC pressure sensor data through our CFD software. Because we knew that the data was good, we could use it to test our software," Elvin explains.

The data from Bloodhound's strain gauges will similarly be compared with finite-element analysis strain models. Discrepancies could well indicate regions that need reinforcement. One area where strain was a major concern for Thrust SSC was the steering: Green had to fling the steering wheel from side to side to keep the car running straight, and at one point he wrenched the wheel off the steering column entirely.

Bloodhound's steering wheel is 3-D-printed hollow titanium–light, strong, and molded to fit Green's hands; the team hopes this wheel will withstand anything, although Bloodhound is expected to track much straighter than Thrust did. Green's cockpit instruments include a display of his own design that shows speed, distance, and time to the end of the track. Constant calculation of speed and position, using GPS data and onboard sensors, will give Green a clear indication of when he must trigger the rockets, air brakes, and parachutes. "I hit the buttons, and I know I'll stop at the end of the track," he says.

Green refers to the cockpit as his office. For a few minutes, it'll be the fastest-moving workplace on the face of the earth. ■

POST YOUR COMMENTS at http://spectrum.ieee.org/bloodhound0815

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NANYANG TECHNOLOGICAL UNIVERSITY

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Nanyang Technological University, Singapore

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1) Chemical Engineering candidates with interests in Biochemical Engineering, Synthetic Biology, Food Engineering, Chemical Engineering Process, and Fluids and Colloids.
2) Bioengineering candidates with research interests in Biomaterials, Bioimaging, Biosensors, Biodevices, Bionanotechnologies, Tissue Engineering (musculoskeletal, neuron regeneration, etc), Rehabilitation Neuro-Biomechanics and Translational Biomedical Engineering.

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.

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

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Application Procedure
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The post applied for should be clearly stated. 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 in Robotics and Mechatronics

NAZARBAYEV UNIVERSITY

Nazarbayev University is seeking highly qualified full-time faculty members at the Assistant, Associate and Full Professor levels to join its rapidly growing program in Robotics and Mechatronics in the School of Science and Technology. Successful candidates must have a Ph.D. degree from a reputed research university, a demonstrated ability for research, excellent English-language communication skills and a commitment to graduate and undergraduate teaching and program development.

Launched in 2010 as the premier national university of Kazakhstan, NU's mandate is to promote the emergence of Astana as the research and educational center of Eurasia. The strategic development of this English-language university is based on the Western model via partnerships with top ranking world universities. The university is committed to be a world-class research university and has made significant investments in research infrastructure, equipment and personnel.

Applications are particularly encouraged from candidates with expertise and research interests in the areas of medical robotics, unmanned aerial vehicles, sensor fusion, and mechanical systems design and control. Exceptional candidates with research interests in the broader field of Robotics and Mechatronics are also encouraged to apply.

Benefits include an internationally competitive salary, international health care coverage, free housing (based on family size and rank), child educational allowance, and home-leave travel twice per year.

Applicants should send a detailed CV, teaching and research statements, and list of publications to **sst@nu.edu.kz**. Review of applications will begin immediately but full consideration will be given to applications submitted no later than September 1st, 2015. Successful appointments are expected to begin on January 4th, 2016. For more information please visit **http://sst.nu.edu.kz**.

The South University of Science and Technology (SUSTC)

Professor/Associate Professor/Assistant Professorship in Computer Science

The University

The South University of Science and Technology (SUSTC) is a public institution funded by the municipal of Shenzhen, a special economic zone city in China. Shenzhen is a major city located in Southern China, situated immediately north of Hong Kong. Shenzhen is China's fast-growing city in the past two decades. The city is the high-tech and manufacturing hub of southern China. Shenzhen is also a popular tourist destination and was named one of the world's 31 must-see tourist destinations in 2010 by The New York Times.

SUSTC is a pioneer in higher education reform in China. The mission of the University is to become a globally recognized institution which emphasizes academic excellence and promotes innovation, creativity and entrepreneurship. The teaching language at SUSTC is bilingual, either English or Putonghua.

Call for Application

SUSTC now invites applications for the faculty position in Computer Science Department. These positions are full time posts. SUSTC adopts the tenure track system, which offers the recruited faculty members a clearly defined career path.

Candidates should have demonstrated excellence in research and a strong commitment to teaching. A doctoral degree is required at the time of appointment. Candidates for senior positions must have an established record of research, and a track-record in securing external funding as PI.

To apply, please send curriculum vitae, description of research interests, statement on teaching and at least three letters of recommendation to cshire@sustc.edu.cn.

STC offers competitive salaries and fringe benefits, which are among the best in China. More information can be found at **http://www.sustc.edu.cn/en**.

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

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Joint Research Institute

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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

SCHOOL OF MEDICINE

CASE WESTERN RESERVE UNIVERSITY

Assistant/Associate Professor
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Case Western Reserve University School of Medicine
Department of Biomedical Engineering

The Department of Biomedical Engineering in the School of Medicine and the Case School of Engineering at Case Western Reserve University invites applications for a tenure-track faculty position in the area of informatics in image guided interventions at the level of Assistant or Associate Professor. Candidates should have a doctorate and post-doctoral research experience in computer science, electrical engineering, biomedical engineering or a closely related field, an outstanding record of research achievements, and ability to contribute to the departmental educational mission. Physician scientists are strongly encouraged to apply. Faculty in this position will have the opportunity to build upon the existing CWRU strengths in related methodologies of computer aided diagnosis, imaging methodology, multi-modal image fusion for treatment targeting, monitoring, and evaluation. Representative areas for IGI research include directing and evaluating radiofrequency ablation, deep brain stimulation, and image guided drug delivery. Opportunities exist for interdisciplinary, inter-institutional, and integrative research in the areas of surgery, radiology, cardiovascular disease, urology, neurosurgery, and radiation oncology. Preference will be given to candidates with a record of national funding and strong interest in translational and team science based research. The successful candidate will have a primary appointment in the Department of Biomedical Engineering in the School of Medicine.

Please send curriculum vitae, a list of three or more references, and a cover letter outlining your research interests electronically to: igi-facultysearch@case.edu. Please include "Image Guided Interventions Faculty Search" in the subject line.

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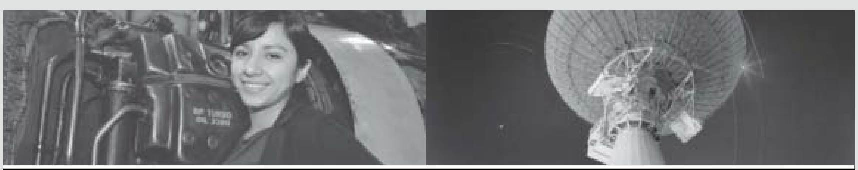

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PROFESSORS-RESEARCHERS

DEVICE ARCHITECTURE – DESIGN – PROTOTYPING/FABRICATION – INTEGRATION (AP 15-02)

CENTRE ÉNERGIE MATÉRIAUX TÉLÉCOMMUNICATIONS (four tenure-track positions)

SUMMARY

Institut national de la recherche scientifique (INRS) is a graduate and post-graduate research and training university. One of Canada's leading research universities in terms of grants per professor, INRS brings together some 150 professors and more than 700 students and postdoctoral fellows in its centers in Montreal, Quebec City, Laval, and Varennes. Conducting fundamental research essential to the advancement of science in Quebec as well as internationally, INRS research teams also play a critical role in developing concrete solutions to problems facing our society.

The Centre Énergie Matériaux Télécommunications seeks to fill four tenure-track positions of professors-researchers in device architecture, device design, device prototyping/fabrication, and device integration. The successful candidates will join a vibrant environment where about forty professors-researchers undertake leading-edge research and training in diverse fields of energy, materials, photonics and telecommunications. The Centre is currently located on two sites, in the city of Montreal and in Varennes (South Shore of Montréal).

The Centre hosts unique major research facilities including the Advanced Laser Light Source (ALLS) and the Laboratory of Micro and Nanofabrication (LMN) that form the Infrastructure of Nanostructures and Femtoscience (http://lmn.emt.inrs.ca/EN/inf.htm), and the Microwave and Wireless Laboratories. In addition to the availability of these unique facilities, we offer competitive start-up packages.

We seek to hire the best candidates with advanced expertise in device architecture, device design, device prototyping/fabrication and device integration, as well as in device testing and optimization at the component-, link- and system-levels. Technologies of interest include electronic, optical/photonic, optoelectronic, radio-frequency (RF), and acoustic/ultrasound devices for applications aimed at, but not limited to: sensing; metrology; telecommunications; control and automation; energy conversion saving, transfer, and storage; health; transport; etc.

The chosen candidates are expected to establish collaborations with research teams already in place, while developing or maintaining national and international partnerships outside the Centre. They will have the opportunity to bridge our expertise and established activities in advanced materials, photonics and telecommunication and energy systems.

REQUIREMENTS

- A Ph.D. degree in an appropriate field (electrical engineering, engineering physics or related).
- An outstanding record of research accomplishments that will enable her/him to successfully develop a strong, independent and externally funded research program.
- The aptitude for supervising graduate students and postdoctoral fellows and teaching graduate level courses.
- The ability to work in a multidisciplinary team and within research networks.
- The background and aptitude to collaborate with industrial partners and build long term partnerships.

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- French is the working language of the Institute. Fluency in English is required.
  Candidates whose native language is not French are encouraged to apply. The Centre will provide them with all the resources necessary to facilitate their learning of the French language.

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SALARY

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HOW TO APPLY?

Interested applicants must forward, by email and registered mail, a complete curriculum vitæ, a copy of their three most significant publications, a two to three page summary of their research interests, a statement of teaching philosophy, as well as the names and contact information of three referees, by September 30, 2015, indicating the position number AP 15-02:

Dr. Federico Rosei, Professor and Director
Centre Énergie Matériaux Télécommunications
1650, boul. Lionel-Boulet, Varennes (Québec) J3X 1S2
rosei@emt.inrs.ca

Note: Only shortlisted candidates will be contacted. Interviews are expected to take place during the autumn term of the 2015-2016 academic year. These positions are to be filled in the 2015-2016 academic year.

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BEFORE FACETIME OR SKYPE, THERE WAS THE PICTUREPHONE

In the 1960s, AT&T and its manufacturing subsidiary, Western Electric Co., became convinced that the next big thing would be a video telephone on every desk. With great fanfare, AT&T launched the first Picturephone service in 1970, confidently predicting a million sets in use within the decade. But the offering was a spectacular flop. Its failure can be variously attributed to networking issues (it only worked if the person you were calling also had one); high cost (a lease was US $160 a month—about $970 in today's dollars); and, most damning, general dislike. The Picturephone was, by default, always on, and people just did not want to be seen all the time. The irony, of course, is that today's consumers most definitely do like to be seen, so long as they can choose when that happens. Through free services such as FaceTime and Skype, video telephony is now readily available, albeit on computers and smartphones, rather than dedicated sets operated as part of a wired telephone network.

—SHELDON HOCHHEISER

PHOTOGRAPH BY Randi Klett


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