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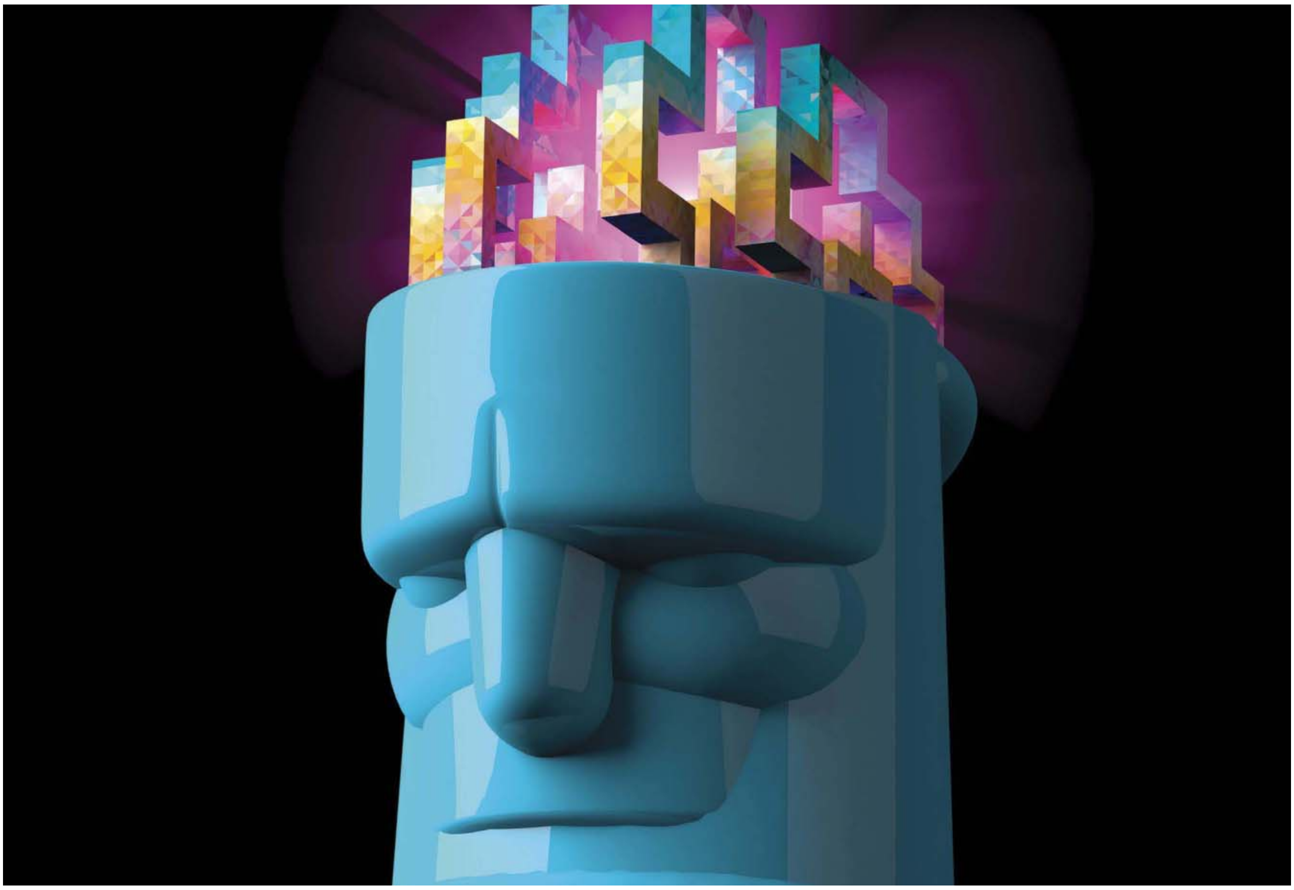

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On the Cover **Illustration for *IEEE Spectrum* by Carl DeTorres**

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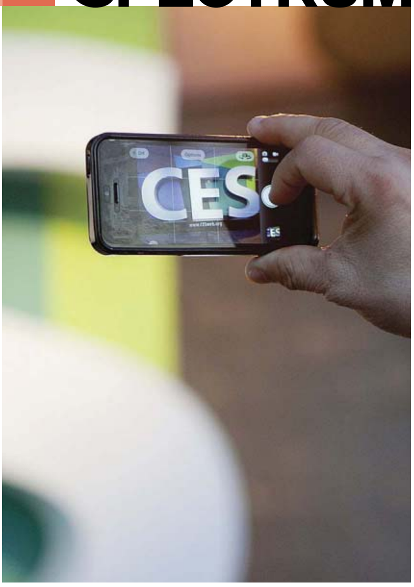

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BACK STORY_

Drone's-Eye View

THIS ISSUE OF *IEEE Spectrum* surveys what the editors expect to be hot topics in the coming year. In "Open Season on Drones?," Senior Editor David Schneider writes about the increasingly contentious debate on the use of small camera-laden drones, a subject that's close to his heart because he flies small camera-laden drones himself, for fun. "I've been flying radio-controlled model airplanes as a hobby since before I could drive," he says. "And in the past few years I've started putting cameras on them. That makes them no different, really, than the kinds of drones I write about in this issue."

His initial impetus for giving his models imaging capabilities was the desire to fly in a mode known as first-person view, using video cameras and radio downlinks to simulate the sensations of flying while piloting a model from the ground. "Then I discovered a segment of the modeling community using their planes for aerial photography, which I started doing too, just to be able to take some pretty pictures." (Schneider is shown above pursuing this pastime in northern Arizona at an entrance to Glen Canyon National Recreation Area.)

"It hadn't occurred to me until I wrote about the privacy implications of drone regulation that people might get bent out of shape about *my* flying a camera over their heads," Schneider muses. "I suppose few would truly get upset about this little hobby—until they have a camera-equipped quadcopter hovering over their backyard hot tub, that is." ■

01.14

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PHOTOGRAPH BY David Schneider

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W. Wayt Gibbs

Gibbs is a freelance science writer in Seattle and a former editor at *Scientific American*. He has worked with Nathan Myhrvold at Intellectual Ventures on a variety of projects and was editor in chief of *Modernist Cuisine: The Art and Science of Cooking*. In this issue, Gibbs turns his hand to creating a tiny DIY synthesizer with metallic ink ["Brew Your Own Conductive Ink," p. 18]. It's "exciting that artists could use this kind of ink to incorporate electronics organically into their creative works," he says.

Brandon Keim

Keim, a correspondent for *Wired Science* and a freelance science journalist, was skeptical about the U.S. government's massive initiative to map the human brain. "I had some existential issues with it," he says, adding that he initially found the project overambitious and ill-defined. But in the course of reporting "Big Science Takes on the Brain" [p. 37], he spoke to neuroscientists who were dividing that daunting task into more achievable goals. "It's great that it's going forward," he says now.

David Kushner

An *IEEE Spectrum* contributing editor, Kushner often writes about hacking, social media, and computer gaming. In this issue, he looks at the Oculus Rift, a headset that, after many false starts, could bring virtual reality into the mainstream [see "Virtual Reality's Moment," p. 26]. "VR has been the holy grail of geekdom for decades, but now, especially with John Carmack [cocreator of *Doom*] on the Oculus team, it could finally be a reality," says Kushner.

Maggie McKee

A freelance journalist based in Boston, McKee reports on the first flight of NASA's new deep-space crew capsule, the Orion spacecraft, in "To Low Earth Orbit and Beyond" [p. 50]. McKee has covered space for more than 10 years. But despite a trip out to ESA's space center in Kourou, French Guiana, she's never managed to see a rocket take off. "I seem to have very bad luck with launches," McKee says. She's hoping the stars will align with Orion.

Stuart Nathan

Nathan is an aficionado of Formula One, a street-based auto racing series that sometimes pioneers technologies that later appear in passenger cars. In "The Fast and the Formula E" [p. 35], he explains how an all-electric version of that series is likely to change the image of e-cars, now only "one step along from their previous image, which was as glorified golf carts." Nathan is the features editor of *The Engineer*, in London.

PHOTO-ILLUSTRATIONS BY **Gluekit**

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How We Began

A half century ago, a small group of engineers had a radical idea: Create the kind of magazine they themselves would want to read

FIFTY YEARS AGO THIS MONTH, members of the IEEE got the first tangible benefit of their membership—a fat, glossy magazine with a jazzy red pattern on the cover. Inside, the magazine's volunteer editor, a plainspoken, 56-year-old engineering dean from the Midwestern United States named John D. Ryder, launched the first-ever Spectral Lines column with a hearty hello.

"Greetings!" he wrote.

So began a singular experiment in magazine journalism. *IEEE Spectrum* has never been an academic journal, but it hasn't been a consumer magazine, either. From its very first issue, *Spectrum* was something unique in publishing: an authoritative and yet accessible voice on technology. In a single issue, it might explain the details of a new semiconductor process, with a level of readability lacking in a trade magazine, and also reveal and analyze irregularities in a vast government IT procurement, with the authority and insight lacking in a newspaper account.

IEEE SPECTRUM 1964 / 2014

In this 50th anniversary year of *IEEE Spectrum*, we will be using the Spectral Lines column to describe some pivotal moments in the magazine's history. And we'll start here with the first issue: January 1964.

Spectrum sprang from the event that created the IEEE—the gloriously tumultuous merging, in 1963, of the American Institute of Electrical Engineers and the Institute of Radio Engineers. The AIEE and the IRE each had a publication of note: The AIEE's was called simply *Electrical Engineering*; the IRE had the *Proceedings of the IRE*, an archival journal. The volunteer officers of the new IEEE wanted to create a flagship publication. But what should it be?

Remarkably, they agreed it should be a *magazine*, not a journal, with articles that were solid, compelling, and timely. They soon ratified a plan designed to establish a magazine that members would actually *read*.

What was so bold about that? Plenty. Association publications are all too often dreary repositories of self-congratulatory articles and antiseptically sanitized editorial material. The association's leaders micromanage editorial operations and avoid controversial but vital topics. That's a shame, because you can't produce good journalism while avoiding controversy. It's like trying to be a good sailor while avoiding wind.

Spectrum was, and is, a marvelous fluke. It is what it is today in large measure because a small group of men believed that a great professional society should give its members a great magazine. Besides Ryder, the clique included Donald G. Fink, the first general manager of the IEEE and a former editor of the legendary McGraw-Hill magazine *Electronics*; Alfred N. Goldsmith, a revered radio engineer and a founding member of the IRE; and Elwood K. ("Woody") Gannett, who had managed the IRE's *Proceedings*.

These people knew what kind of magazine they wanted, but only Fink had experience in managing such a publication, and he was busy running the fledgling IEEE. So Ryder and Gannett started by

PHOTOGRAPH BY Randi Klett

hiring a few publishing professionals, including Ronald K. Jurgen, Samuel Walters, and Gordon D. Friedlander, who had backgrounds or degrees in engineering but had made their careers in journalism. They also hired a professional art director and resolved to print the covers in color–again, hot stuff in those days for an association magazine.

At the top of the masthead, though, *Spectrum* kept with tradition by listing a volunteer official–Ryder–as "editor." (Ryder's actual title, though, was chairman of the IEEE Editorial Board.) He wisely left the day-to-day operations of the magazine in the hands of Gannett, who is listed on the masthead of that first issue as "managing editor." Gannett had a bachelor's degree in electrical engineering, but he had spent nearly all of his career as a publications staffer at the IRE. By all accounts, Gannett, the only experienced editorial holdover from the IRE, navigated the inevitable teething pains of those early years with good humor and patience.

That first issue of *Spectrum* is a sprawling and eclectic mix. (The issue is available for download at http://spectrum.ieee.org/firstspectrum0164.) There are a few hardcore features–"High-power solid state devices," "EHV ac and dc transmission," and "New coherent light diffraction techniques." The articles are an odd hybrid: full of equations but with magazine-style introductions and illustrations. It's clear they were edited for–gasp–readability.

There's a high-minded feature by Goldsmith, who had been the volunteer editor of the IRE's *Proceedings* for 42 years, starting in 1913. The piece is titled "IEEE Spectrum–Retrospect and Prospect," but about halfway through it veers away from *Spectrum* to reflect on the IEEE's purpose and mission. The writing seems a tad florid today, but the article is ultimately touching: The IEEE "is no more and no less than a reflection of our hopes, our ideals, our professional dedication, and our sense of our value to each other and to the world," Goldsmith wrote. "It is ours to mold, to change, to guide, and to re-create in an increasingly worthy form."

From the beginning *Spectrum* staked out a broad view of what would constitute suitable subject matter. The first issue's lead feature ranges far afield from electrical engineering: It's a mathematical musing on how the universe would appear to voyagers on a starship traveling at a relativistic velocity. The author, Bernard Oliver, was then vice president of R&D at Hewlett-Packard and a member of the IEEE

SPECTRAL LINES_

Editorial Policy Committee, which had approved Ryder's plan for *Spectrum*. Oliver would go on to help establish the search for extraterrestrial intelligence as a legitimate field of endeavor.

The list of advertisers in that first issue of *Spectrum* is impressive. The roster includes many of the major high-tech organizations of the time: IBM, GE–which took out four separate ads–Texas Instruments, Fairchild, 3M, TRW, Lockheed, Hughes, Lincoln Laboratories, Jet Propulsion Laboratory, Toshiba, and Amphenol, among them. And, like photos of deceased relatives, some of the ads remind us of the dearly departed: Burroughs, Univac, Sperry, and General Radio Co. Devices and gear of that bygone era are also well represented, with advertisements for resistors from Allen-Bradley, capacitors from Sprague, and meters from Simpson and from Triplett. Hewlett-Packard has a plug for its 3440A digital voltmeter, with a Nixie-tube display. Price: "only" US $1295–about $9500 in today's dollars. Tektronix boasts that its new Type 647 oscilloscope is solid state and "convection cooled–no fan needed."

> The first feature in the first issue of *Spectrum*: a mathematical musing on how the universe would appear to voyagers on a starship

Besides being founded by smart and perceptive people, *Spectrum* also had the good fortune to be born at a pivotal and surging time in electronics. In 1964, transistors were muscling out vacuum tubes (that year, Sharp would introduce the first transistor-based calculator). And integrated circuits, invented just five years earlier, were starting to find markets in the military and in aerospace. Thus in that first issue you'll find an ad for a directory of electron tubes, as well as one for Motorola transistors, and another from Texas Instruments touting "Growth Opportunities for Silicon Engineers."

The people who established *Spectrum* could scarcely have imagined the multimedia operation that their print magazine would evolve into. But it's a testament to their vision that the magazine they brought into the world would go on to reap hundreds of editorial honors and awards in the United States, including five National Magazine Awards and three Grand Neal Awards. No other association magazine can claim such a trove. (Pardon the self-congratulation here, but we figure it's okay to pat ourselves on the back once every 50 years.)

In the end, what would have pleased *Spectrum*'s founders most is that they established a media operation that decades later still engages, informs, and frequently delights. It's one that helps keep the wider world aware of the IEEE while weighing in on critical technology issues with the authority often lacking in the mainstream press. Goldsmith, in his primordial editorial, had hoped for just that. *Spectrum*, he promised, would "inherently aim to be an agent for human progress." He and his colleagues worked prodigiously to make that happen. Now, 50 years later, it is our honor to keep their vision alive. –GLENN ZORPETTE

NEWS

0

GOOGLE'S NET CARBON FOOTPRINT IN 2012 AFTER PURCHASING OFFSETS

JON FEINGERSH/GETTY IMAGES

REDUCING THE CARBON COST OF CLOUD COMPUTING

Software redistributes tasks among networked data centers to optimize energy efficiency

The computing cloud may feel intangible to users, but it has a definite physical form and a corresponding carbon footprint. Facebook's data centers, for example, were responsible for the emission of 298 000 metric tons of carbon dioxide in 2012, the equivalent of roughly 55 000 cars on the road. Computer scientists at Trinity College Dublin and IBM Research Dublin have shown that there are ways to reduce emissions from cloud computing, although their plan would likely cause some speed reductions and cost increases. By developing a group of algorithms, collectively called Stratus, the team was able to model a worldwide network of connected data centers and »

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predict how best to use them to keep carbon emissions low while still getting the needed computing done and data delivered.

"The overall goal of the work was to see load coming from different parts of the globe [and] spread it out to different data centers to achieve objectives like minimizing carbon emissions or having the lowest electricity costs," says Donal O'Mahony, a computer science professor at Trinity.

For the simulation, the scientists modeled a scenario inspired by Amazon's Elastic Compute Cloud (EC2) data center setup that incorporated three key variables–carbon emissions, cost of electricity, and the time needed for computation and data transfer on a network. Amazon EC2 has data centers in Ireland and the U.S. states of Virginia and California, so the experimental model placed data centers there too, and it used queries from 34 sources in different parts of Europe, Canada, and the United States as tests.

The researchers then used the Stratus algorithms to optimize the workings of the network for any of the three variables. With the algorithms they were able to reduce the EC2 cloud's emissions by 21 percent over a common commercial scheme for balancing computing loads. The key to the reduction, scientists found, was in routing requests to the Irish data center more than to those in California or Virginia. Ireland also tended to have faster-than-average service request times, so even when Stratus was tuned to reduce carbon, it shaved 38 milliseconds off the average time taken to request and receive a response from the data centers.

The researchers stress that the results have more value in representing trends than in predicting real-world numbers for quantities like carbon savings. Some of the key inputs were necessarily inexact. As an example, for some geographic locations, such as Ireland, it was easy to find real-time carbon intensity data or real-time electricity pricing data, but in other areas, including the United States, only seasonal or annual averages were available. "If we had the real-time data for California and Virginia, the simulations might look quite different," says Joseph Doyle, a networks researcher at Trinity who worked with O'Mahony and IBM's Robert Shroten on Stratus.

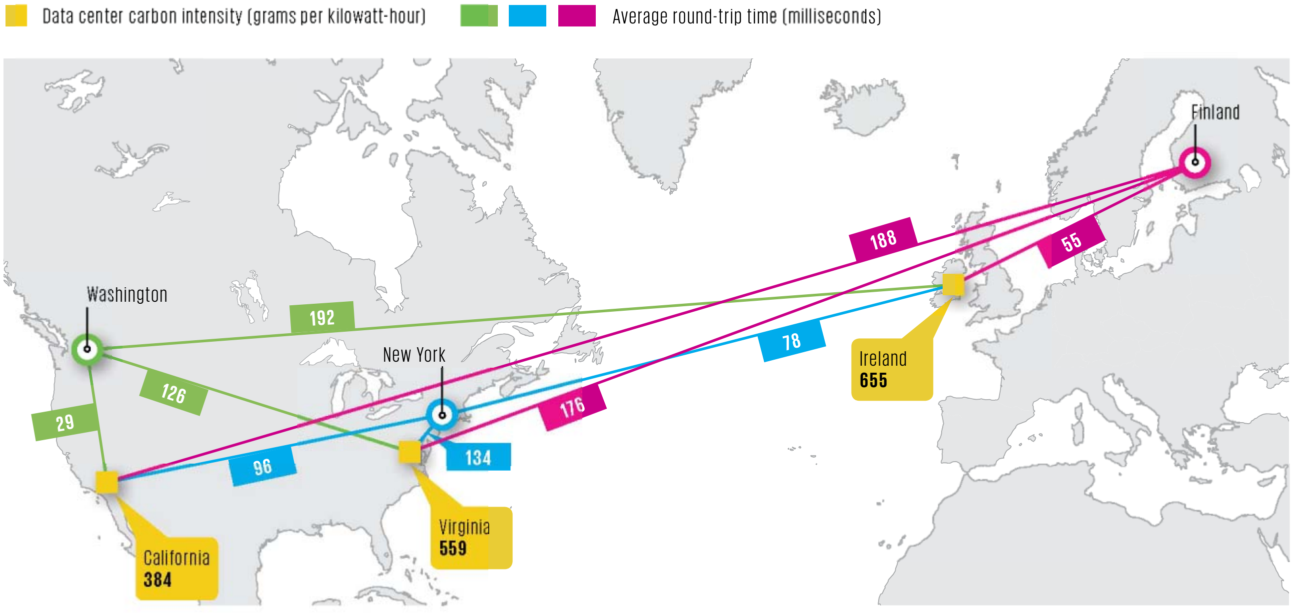
Christopher Stewart, who researches sustainable cloud computing at Ohio State University, says that although Stratus and other recent work have made significant progress toward modeling effective load balancing, data storage is another important factor to consider. In order to handle requests, you have to have data stored on-site, he says. "With data growing rapidly, storage capacity is a major concern now, too, and that may limit your flexibility in terms of being able to route requests from one data center to another."

The researchers hope that the easier it is to achieve load balancing and optimization in cloud computing, the more it will be implemented by environmentally conscious companies, or those just looking to save money. "A company like Twitter might have lots of options in how it decides that all the Twitter traffic is going to get served around the world," O'Mahony says. "If they decided that greenness was one of the things that was most important to them, they could structure their load balancing accordingly. Or if getting it done as cheaply as possible was important, they could structure it that way. Or they could do anything in the middle."

—LILY HAY NEWMAN

Cloud Computing and Carbon Dioxide

Algorithms route requests from different sites [circles] to data centers [yellow squares] by balancing round-trip travel time and the data center's carbon footprint.



SOURCE: "STRATUS: LOAD BALANCING THE CLOUD FOR CARBON EMISSIONS CONTROL," BY JOSEPH DOYLE ET AL., ACCEPTED FOR PUBLICATION IN *IEEE TRANSACTIONS ON CLOUD COMPUTING*

COMPOUND SEMICONDUCTORS JOIN THE RACE TO SUSTAIN MOORE'S LAW

Chip leaders fabricate silicon wafers with transistors containing exotic semiconductors

Engineers at Imec and IBM have independently developed new manufacturing processes for making the next decade's leading chips, they revealed late last year.

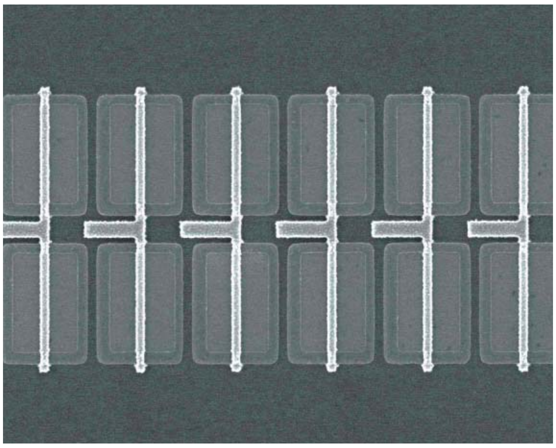
These efforts will allow the marriage of silicon wafers and certain exotic materials–compound semiconductors with ingredients from columns III and V of the old periodic table. This mixing of materials holds the key to maintaining the traditional performance improvements associated with Moore's Law and the shrinking of transistor dimensions.

Both Imec and IBM have built highly efficient transistors with the III-V semiconductor indium gallium arsenide. Electrons can zip through this material six times as fast as they can through silicon. Thanks to this speed, it's possible to cut a transistor's operating voltage while maintaining the amount of current flowing through it, thereby trimming power consumption.

Engineers at Imec, in Leuven, Belgium, revealed their breakthrough first, announcing in November that they had taken an industry-standard 300-millimeter silicon wafer and formed fin-shaped field-effect transistors. FinFETs are the type of 3-D transistor deployed in the most advanced microprocessors. The Imec devices replaced the FinFET silicon channel with one made of indium gallium arsenide.

Dean Freeman, an analyst at Gartner, believes that this type of channel could make its debut as early as the 7-nanometer node, the generation of chips due to market in as little as four years. "I don't want to put words in Intel's mouth, but there is a potential that we could see this FinFET technology emerge into very-high-end servers," he says.

Smartphones could also benefit, because the altered channels would increase battery life and reduce the number of chips in a phone. Today, in most cases, a mobile phone uses a III-V chip to amplify wireless signals and a separate silicon chip for data processing. The recent breakthroughs could let a single chip carry out both tasks.



CHANGING THE CHANNEL: IBM engineers made transistors with indium gallium arsenide and silicon germanium components on the same silicon wafer.

IBM ZURICH RESEARCH LABORATORY

Imec forms its FinFETs by taking a silicon wafer and etching trenches into it that are just tens of nanometers wide. Each trench is filled with indium phosphide before indium gallium arsenide is added to produce the protruding fin of the transistor.

Using a trench reduces crystal defects in the transistor channel. Depositing indium phosphide on silicon always leads to defects, because of the 8 percent difference in the average spacing of the atoms in these two crystals. However, these defects–missing planes of atoms aligned at about 45 degrees to the wafer surface–terminate at the trench walls, enabling the growth of high-quality material near the wafer surface.

"I do not want to claim that [the channel] is completely defect-free," says Aaron Thean, director of Imec's R&D program on logic devices, "but it's definitely good enough for the transistor to work now."

At the IBM Zurich Research Laboratory, engineers use entirely different processes. Their approach, which Lukas Czornomaz described at the IEEE International Electron Devices Meeting (IEDM) held in Washington, D.C., in December, begins by forming a substrate composed of a 6-nm-thick film of indium gallium arsenide and an 8-nm-thick layer of silicon germanium, separated by a thin insulator.

Introducing silicon germanium allows the production of CMOS circuits because it enables the formation of high-speed transistors based on the movement of holes–essentially the positive counterparts to electrons. With the new process, "we demonstrate, for the first time, a hybrid, high-mobility CMOS circuit on insulator, where we have small *n*- and *p*-transistors based on these two materials on the same substrate," says Czornomaz.

He claims that such engineered substrates offer three benefits for integrated-device manufacturers: very low leakage currents, thanks to the insulating layer beneath the devices; relatively minor adjustments to the foundry processes, because the challenges of introducing new materials are shifted to the substrate supplier; and tremendous freedom for the circuit designer to select the size and position of the transistors. In Imec's trench scheme, III-V semiconductors and

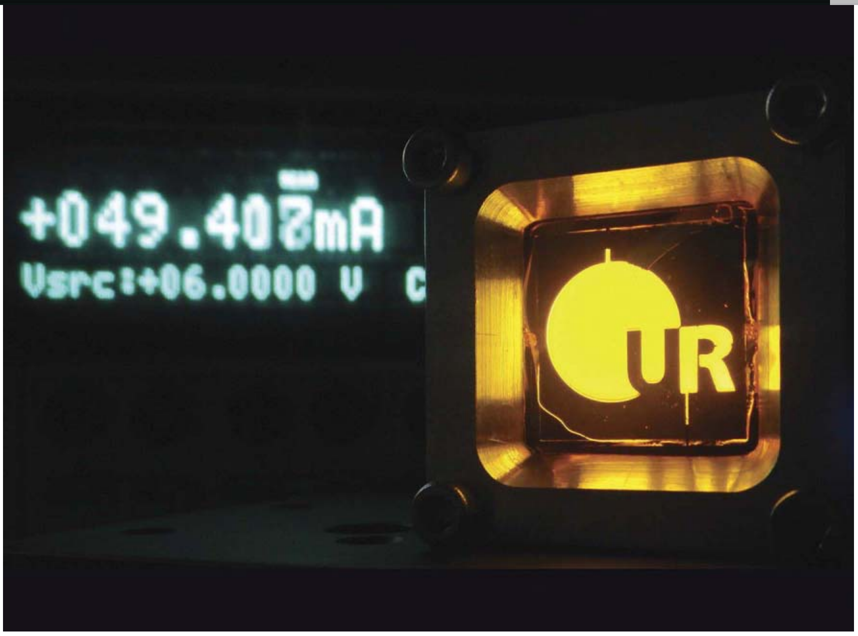
NEWS

silicon germanium are present only in defined areas of a wafer, but with IBM's approach, these materials are everywhere.

The engineers at IBM Zurich used their process to build an inverter operating at 0.5 volt. That's 0.3 V less than the voltage used in state-of-the-art silicon FinFETs, leading to 60 percent lower power consumption. Imec's transistors also operate at 0.5 V, delivering a performance that Thean describes as "almost as good" as a silicon equivalent.

In separate research, Czornomaz's colleagues at IBM's T.J. Watson Research Center, in Yorktown Heights, N.Y., appear to have done even better than that. "The intrinsic performance of [our] device is better than silicon, if we compare the same dimensions," says Yanning Sun of IBM Watson. At IEDM, she detailed the results of indium gallium arsenide transistors with a 30-nm gate length—about the dimensions of a leading-edge transistor from 2010. The devices were formed on an indium phosphide substrate using CMOS-compatible processes.

At IBM Watson and at Imec, engineers will now try to shrink their transistor dimensions to enable a true comparison with state-of-the-art silicon. Meanwhile, the team at IBM Zurich will aim to increase the size of the engineered wafer from 100 to 300 mm and to build a static RAM cell, a compact, six-transistor memory cell common on microprocessors. "If someone can show 0.5-volt SRAM on silicon germanium and III-Vs, it's a big step ahead," says Czornomaz.
—RICHARD STEVENSON



UNIVERSITY OF REGENSBURG

SPIN TRICK COULD MAKE OLED DISPLAYS CHEAPER

Molecules manipulate electron spin to increase light emission without the aid of iridium and other rare metals

A new way of coaxing light out of an organic LED may make for cheaper displays and could even provide a way to see magnetic fields.

By choosing a molecule of a particular shape, a team of German and American researchers designed a new type of OLED that has the potential to emit as much light as a commercial OLED, but without the rare metals normally added to make the devices efficient. If manufacturers could leave out metals such as iridium or platinum, they might not have to worry about potential shortages of these elements. This would allow them to bring down the costs of OLEDs, which are increasingly being used in the screens of smartphones and televisions, as well as in solid-state lighting.

OLEDs convert only a fraction of the electrical current they receive into light. That's because of a quantum mechanical property of the electrons and their positive quasiparticle counterpart holes, called spin. Spin is what gives rise to magnetism; when the spins of a majority of electrons in a material point in the same direction, the material is magnetic. Each electron and each hole can exist in one of two spin states, so when they pair up there are four possible states, three of which dissipate their energy as heat rather than light. This means that only a quarter of the electricity put into the device produces light. OLED makers add metal to the hydrocarbon molecules in their devices to mix up the spin states and increase the number of light-generating combinations.

But it's also possible for some of the spins to switch to the more light-friendly version on their own, says John Lupton, a physicist at the University of Regensburg, in Germany, who was part of the team that did the work. "You just have to wait long enough for this spin state to spontaneously relax," he says.

If an electron-hole pair can be held in its electrically excited state long enough for one spin to flip, when it drops to a lower energy state it'll emit the extra energy as a photon rather than as heat, Lupton explains. "Long enough" is measured in milliseconds, com-

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CERTIFIED ORGANIC: New OLEDs shine brightly even without the usual rare metal additives.

pared with the nanoseconds it usually takes for emission to occur, a difference of six orders of magnitude.

The trick, which the researchers from Regensburg, the University of Bonn, the University of Utah, and MIT explain in a paper published online by *Angewandte Chemie*, lies in the shape of the organic molecules used in the LED. The researchers developed two kinds of polycyclic aromatic hydrocarbons (carbon-based molecules having multiple ring-shaped components): one called phenazine and the other triphenylene. The atomic structures of the molecules were such that they trapped the charge carriers long enough for the spontaneous change to occur. A peculiarity of the molecule–the researchers speculate that it may have to do with different energy characteristics in different areas of the molecule–prevents the extra energy from being released as heat before the spin can flip. "Because of their shape, you can localize the electron density and therefore the spin density in specific areas in the molecules," Lupton says, adding that the result was surprising to the researchers, who were actually studying other facets of OLEDs. "If you look at textbooks of physical chemistry, this should not have actually worked," he says.

Last year another group, led by Chihaya Adachi at Kyushu University, in Japan, demonstrated its own method for making OLEDs without the use of metal. The researchers designed a molecule that relies on fluorescence for light emission, instead of the phosphorescence used in most metal-reliant OLEDs. Their mechanism, called thermally activated delayed fluorescence, takes the heat released by some of the charge carriers and uses it to bump up the energy level of others to the point that they emit light instead of heat when they relax. The Kyushu scientists say their material has an internal efficiency of nearly 100 percent, which translates into about 14 percent of the electricity pumped into the OLED reemerging as light, compared with about 20 percent in commercial OLEDs that use metal.

Alán Aspuru-Guzik, a chemist at Harvard, sees the work by Adachi and Lupton as developments "that could lead to a breakthrough in the field of OLEDs." The work both groups are doing could lead to better emission in the blue end of the spectrum in particular. Blue organic light emitters have been the most difficult to develop.

At the moment, the price of rare metals needed in OLED manufacturing is so low that manufacturers are unlikely to need either trick soon. And this new method doesn't actually improve OLED efficiency over what existing devices can deliver, says Lupton. But it could prove appealing to OLED manufacturers if the price of iridium goes up.

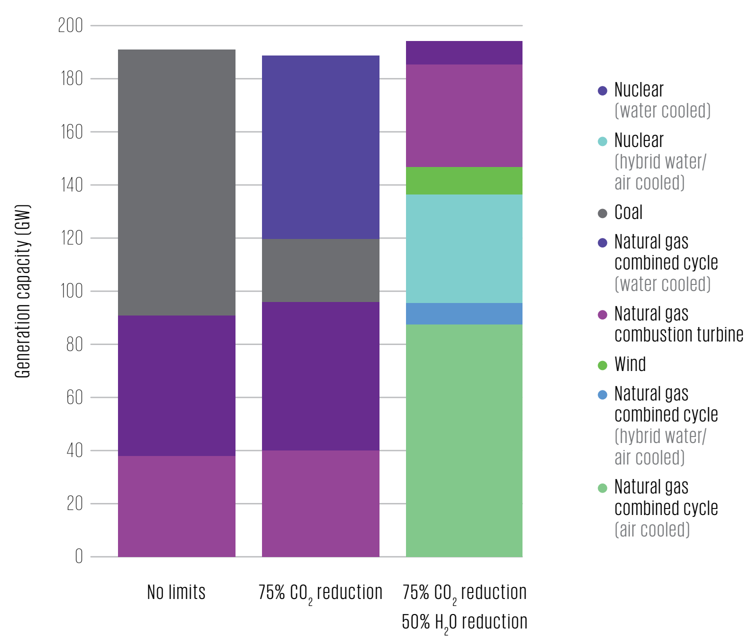
Far more interesting may be another aspect of Lupton's discovery: The spins of the charge carriers in this type of OLED control the wavelength of the light emitted. "You can actually measure the spin of the electron within your OLED by using the color," Lupton says. And because spin on the quantum level translates into magnetism in the macro world, "if you design this in the right way you could make it incredibly sensitive to magnetic fields," Lupton says. "That will actually allow us to use the color of the OLED as a compass." He says such a device could be more sensitive than Hall effect devices, which are common in smartphone navigation systems and in automobiles, where they measure the rotation of the wheels.

The research might even provide a new clue to how birds navigate using Earth's magnetic field. While the exact mechanism is still debated, some scientists suspect that their eyes let them see shifts in the field as subtle variations of color. Lupton says they may be sensitive to color changes caused by alterations in the spins of electrons. –NEIL SAVAGE

NEWS

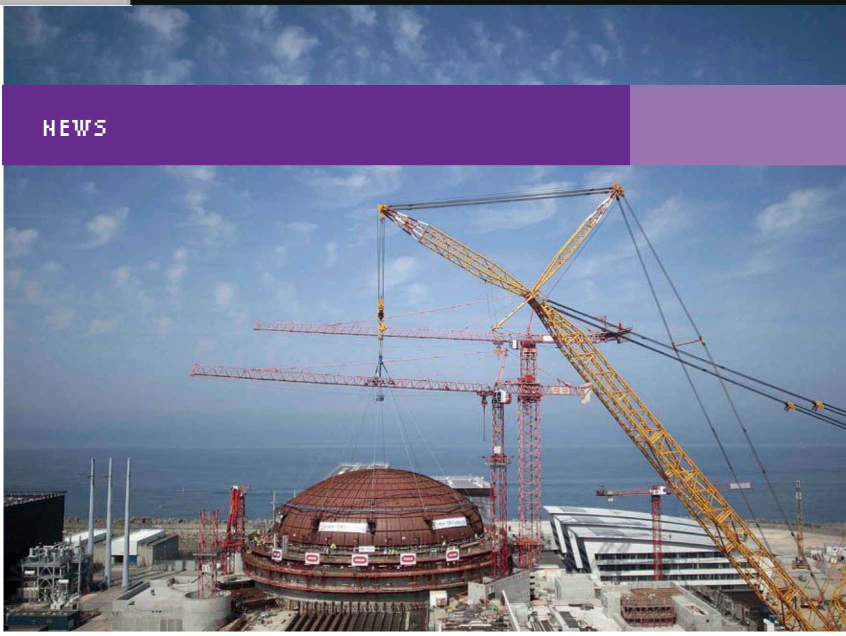
TEXAS, 2050

Texas is peculiar in that it has its own electricity grid. It's not so peculiar in that it recently suffered through a devastating drought. That combination attracted the attention of engineers at MIT. They were looking to model the mix of electricity generation you wind up with in 2050 when you consider different constraints. It's a bit of a no-brainer that you'd get a different mix depending on whether you want to cut carbon dioxide or not. But the more interesting finding is how dissimilar this low-emissions mix is from what you get if you also want to limit water use. The difference in the role of nuclear energy—notoriously thirsty for cooling water—is particularly stark. **—SAMUEL K. MOORE**



SOURCE: "WATER–CO_2 TRADE-OFFS IN ELECTRICITY GENERATION PLANNING," BY MORT WEBSTER ET AL. *NATURE CLIMATE CHANGE*, PUBLISHED ONLINE 27 OCTOBER 2013

NEWS



THE END: This nuclear reactor, under construction in northwest France, could be the country's last.

BRITISH AND FRENCH SWAP NUCLEAR ENERGY POSTURES

The U.K. builds while France scales back

Nations that are considering nuclear energy must grapple with its high capital costs and Fukushima-scale risk. An energy-policy riptide along the English Channel shows how unpredictable the calculations can be: Both France and the United Kingdom have scrapped fundamental planks in their energy policies, with one ramping up and the other dialing down.

In the U.K., where Margaret Thatcher set off a global movement by deregulating the power industry, the current prime minister is offering subsidies to attract financing for new nuclear reactors. Across the water, France, which staked its economic future on nuclear power a generation ago, is now planning that technology's decline. These policy shifts have been in the works since 2012, but they are coming to a head as both governments put the finishing touches on sweeping energy-reform legislation.

A coalition composed of Socialists and the staunchly antinuclear Greens vows to scale back France's reliance on nuclear power from more than three-quarters of electricity at present to roughly one-half by 2025, delivering on a 2012 election promise made by President François Hollande. Legislation to be introduced early in 2014 could include a new nuclear electricity tax, which would help subsidize an accelerated transition toward renewables. A third-generation reactor under construction in Normandy since 2007 could be the country's last.

The British government plans to sustain or even enhance nuclear's role, which was 19 percent of generation in 2012, by proffering taxpayer dollars. Its plan is to inspire construction of a new generation of reactors—enough to provide up to 16 gigawatts of new generation by 2025—by guaranteeing a base price for the electricity. If market pricing falls below that threshold, a government-backed "contract for difference" would make up the shortfall.

There is another layer of irony in the cross-Channel nuclear-policy split: France, which plans to tax nuclear generation, is pushing the U.K. to subsidize it. State-owned utility Électricité de France (EDF) wants to build two 1600-megawatt reactors at Hinkley Point on England's southwest coast, where two 1970s-era reactors could shut down as early as 2023. But EDF insists that without the contract-for-difference guarantee, U.K. power prices, as well as carbon credits that the plant would earn, are too low and uncertain to justify the £16 billion (US $26 billion) investment.

In October, British prime minister David Cameron's government clinched a deal to guarantee EDF approximately £93 ($150) per every megawatt-hour generated at Hinkley Point. That is more than double the average price paid to U.K. generators in 2012, and more than 50 percent higher than the projected price of offshore wind power in 2020, according to the London-based market analyst ICIS.

In the U.K., subsidies for nuclear energy are politically unpopular, but building new nuclear power plants generally garners broad support. New plants would help meet ambitious greenhouse-gas reduction goals that call for a near decarbonization of the electricity system by 2030. The U.K. has made no headway toward capturing carbon dioxide emissions from its fossil-fuel-fired power plants, and offshore wind farms are growing too slowly to help. If aging nuclear plants such as those at Hinkley Point are not renewed, the task becomes that much harder. "What's needed is reliable base-load zero-carbon energy," says Bryony Worthington, shadow minister for energy and climate change in the House of Lords for the opposition Labour Party.

The U.K. government must apply to the European Commission for an exemption to allow its contract-for-difference policy, because European open-market rules limit state aid only to renewable generators. That will be a long road, says Dörte Fouquet, who heads the Brussels office of German law firm Becker Buettner Held and represents the European Renewable Energies Federation. The U.K. will have to show that the subsidy does not have anticompetitive effects. In Finland, for instance, new nuclear generation has saturated the power market and dramatically slowed investment in renewable energy. "This is a huge amount of megawatts being put into a market. If you massively support nuclear, renewables don't have a chance," says Fouquet.

Fouquet predicts that legal challenges against the U.K. subsidy from competing generators will take years to resolve, denying investors such as EDF the certainty they need to start building. So in the end, the British and French may go their separate ways on nuclear policy, but their reliance on nuclear power may yet fade away in harmony. —PETER FAIRLEY

CHARLY TRIBALLEAU/AFP/GETTY IMAGES

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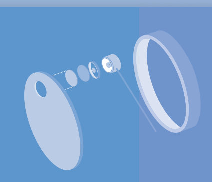
RESOURCES



1952: THE U.S. EMBASSY IN MOSCOW DISCOVERS A SPY BUG IN A CARVING, POWERED BY REMOTE RADIO WAVES—ANOTHER LEON THEREMIN INVENTION.

FRANCIS DZIKWOSKI/ESTO

RESOURCES_REVIEWS

ODD HARMONICS

FRANÇOIS CHAMBARD HAS REVIVED THE THEREMIN WITH HIS BOLD DESIGNS

In the 1920s, Leon Theremin played to packed concert halls in Europe and the United States, wowing audiences with his newly invented electronic musical instrument, the aetherphone. Rebranded as the theremin, the gesture-controlled device was available for sale in the United States by the end of the decade. For a moment it seemed as if it might be able to achieve the kind of success later found by other 20th-century electrical musical innovations such as the electric guitar and the Moog synthesizer. ● But between its unusual style of play—performers move their hands in proximity to two antennas that control pitch and volume—and an expensive price tag during the Great Depression, the theremin failed to make the big time. Not even a burst of enthusiasm for its futuristic, otherworldly sound from the composers of science-fiction film scores in the 1950s could bring it mainstream success. But the theremin never completely went away as an instrument, and it occasionally even finds its way into popular music hits. Now it's having a revival of a different kind—as an art object. ● This past October and November, the Judith Charles Gallery, in New York City, hosted an exhibition titled *Odd Harmonics*. Along with scheduled musical performances, an original Theremin aetherphone, and other artwork, the exhibition focused on a series of theremins constructed by François Chambard. ● Ranging in price from US $6000 to $20 000, Chambard's theremins are whimsical and colorful constructions of wood and metal. The simple antennas of the typical theremin have been replaced with a still-functional assortment of grilles, funnels, sheets, and combs. Each antenna acts as one plate of a variable ▸

ANTENNAS AS ART: Here, volume and pitch are controlled by the orange dish and wire. Wooden knobs control tone and other instrument settings.

capacitor, with the player's body forming the other plate.

These antennas give each theremin a different feel when played, says Chambard, who is a New York City–based furniture designer. The basic sound production system in each theremin is taken from a Moog Etherwave—a commercially produced model used by many modern players—and Chambard worked with technicians to tweak both the system and each new antenna to ensure a good musical response. Chambard says he was drawn to create the series after seeing how intrigued visitors were with a theremin he had included in a show about furniture designed for audio/visual equipment. "It provided a sense of play, of interaction between the user and the object," he says. The theremin's long history was also part of the appeal. The 1920s, says Chambard, were a "time of great invention and creativity," which he hopes his fantastically shaped theremins evoke. **—STEPHEN CASS**

Watch a video of the exhibition, including a theremin performance, with the online version of this article.

BREW YOUR OWN CONDUCTIVE INK

DRAW WORKING CIRCUITS IN PEN AND INK

I'M NOT ASHAMED TO ADMIT IT—MY SOLDERING SKILLS STINK. That puts a real crimp in my ability to prototype circuit ideas. Breadboards work, but by design, they significantly constrain how you can arrange components. ● So I was excited when I spotted a preprint article on ArXiv.org describing a new liquid-metal ink. Conductive inks made from silver nanoparticles have been available for some time; recently, a group at Georgia Tech demonstrated a way to use them in inkjet printers to create custom circuits. But they are quite pricey, and I'm not keen on the idea of pumping metal through my printer. In contrast, this new ink can be used in an ordinary roller-ball pen to draw circuit traces, and the recipe for making the ink is amazingly straightforward: Mix 75.5 parts gallium with 24.5 parts indium in a beaker of deionized water, heat to 50 °C, stir, and voilá: an alloy that's liquid at room temperature, costs about US $1 per milliliter, and is two orders of magnitude more conductive than the nanoparticle inks; its resistivity is just 17 times that of copper. This I had to try. ● I phoned the senior author on the paper, professor Jing Liu of the Technical Institute

LEFT: FRANCIS DZIKOWSKI/ESTO; RIGHT: W. WAYT GIBBS

LIQUID LINES

of Physics and Chemistry at the Chinese Academy of Science, in Beijing, to check that this was really something I could do at home. Use 99.9 percent pure gallium and indium, he advised; I bought the metals from GalliumSource.com for about $130. The pen cartridge needs to be completely clean before filling, and the liquid alloy must be free of any solid bits that might clog the tip. Most important, write on plastic transparencies. The surface tension of the ink is so high that it beads up on paper.

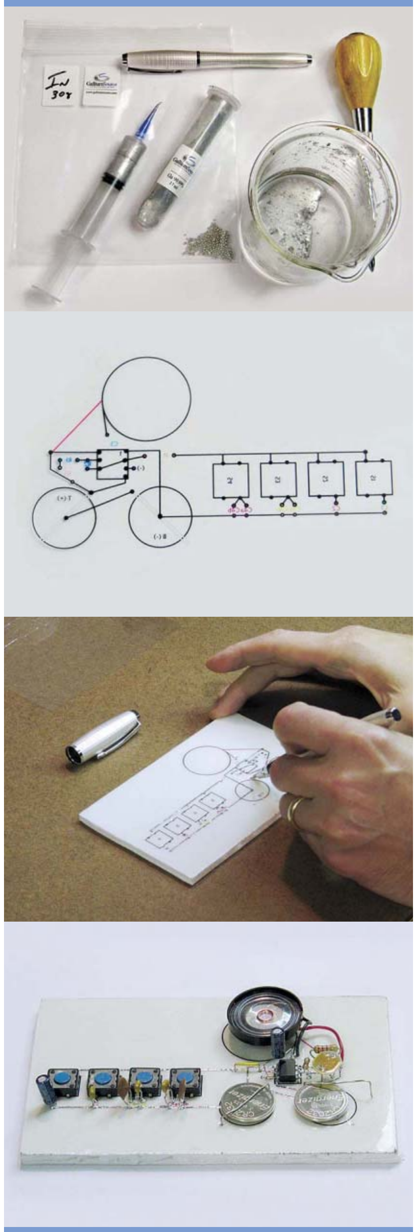
My son's 11th birthday was coming up, so I decided I would try to make a fun gadget—a four-key organ with light-sensitive vibrato—that could go into a birthday card, with the transparency stuck facedown in the card to protect the ink. I settled on a design that uses two 3-volt button-cell batteries, four push-button switches, a photoresistor, a 555 timer integrated circuit, and assorted capacitors and resistors, all linked by hand-drawn traces. But first I'd need to make the ink and fill a pen.

Making the ink was easy. The metals blended readily, and I sucked the conductive ink into a syringe. I bought a high-quality roller-ball pen and some "bold-tip" (0.8 millimeter) cartridges, which I thought would be ideal for dispensing the alloy. Bearing Liu's warning in mind, I realized the tricky part would be getting the regular ink sitting in the cartridges out.

My first thought was to bleed the pen dry. I placed the pen onto a folded paper towel, tip down, and let it sit overnight. Sure enough, the ink wicked away into the towel. I drilled a hole through the metal base of the cartridge, confirmed that it was empty, and squirted in the alloy.

Liquid metal immediately started emerging from the business end of the pen—but not from the roller ball. It was weeping silvery teardrops from air holes a few millimeters up the cartridge and making a terrific mess. (I was glad I was wearing gloves; gallium and indium are not good for your skin.) I plugged the holes with wax—and the pen refused to write. I shook it hard, tried again and—yes! No. It was normal ink that came out, not metal.

I sliced the cartridge open to see what had gone wrong. Inside I found a firmly attached



Blending gallium and indium in a beaker of hot water produced a metallic ink that I used to fill a pen [top]. I marked out my circuit on a plastic transparency and punched holes for components [second from top]. I followed the marks with my conductive ink pen [second from bottom] and inserted components to complete a four-note organ [bottom].

W. WAYT GIBBS (4)

plastic, bottlebrush-shaped wick that was lousy with the original ink. I would need a simpler kind of cartridge.

After two more failed attempts with different cartridges, I finally found an approach that worked. I syringed the ink from the open end of a Uni-Ball Jetstream bold-point pen cartridge and then flushed it repeatedly with denatured alcohol until every drop of the original ink was gone. I dried it under a bright lamp for several hours before squirting in the liquid metal.

"This had better work," I said between clenched teeth as I put pen to transparency. I let out a whoop as the letters I-E-E-E appeared as if in quicksilver. A check with the multimeter confirmed it: virtually no resistance.

I inkjet-printed my circuit pattern, inverted, onto the rough side of a plastic transparency of the sort once commonly used with overhead projectors, and then I drew the traces on the smooth side. Because the ink does not dry, it is easily smeared, but my initial idea of protecting the circuit by sticking it face down was a nonstarter. On contact with a piece of foam board I was using as a backing, the traces spread out and collided, creating short circuits. But I was happy to find that the liquid metal adheres well enough to the plastic that it doesn't run or drip when you upend the sheet. So I stuck the plastic to the board smooth side out, punched holes in the sheet with an awl to accommodate the leads of the components, drew the traces, and then mounted the components.

With great optimism, I pressed one of the buttons, then the others. No sound.

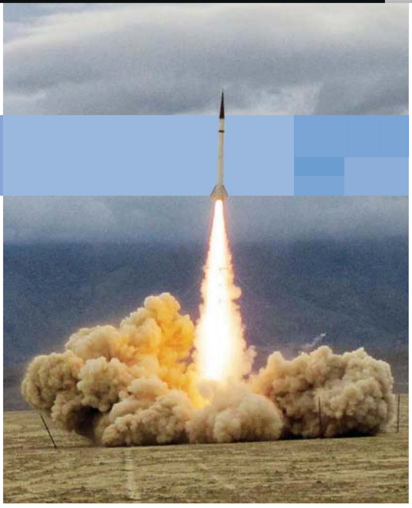
The problem evaded me for hours, until I eventually removed the batteries and saw what was going on. I had forgotten that with button cells, the positive electrode wraps around the rim of the battery: Invisible to me, one such electrode was contacting the inked-in ground lead. A few quick wipes with a cotton swab and the speaker crackled to life.

I tapped out the Mighty Mouse theme: "Here I come to save the day!" Though his birthday had by then passed, my young son got a big kick out of the project, and it provided lots of teachable moments about electronics. And not just for him.

—W. WAYT GIBBS

RESOURCES_EDUCATION

THE YOUNG ROCKETEERS
THEY MAY BE THE FIRST STUDENTS TO LAUNCH A ROCKET INTO SPACE



BEFORE THE BANG: The flight of this rocket—pictured here a moment after launch—ended in an explosion, but work on the next rocket is under way.

USC ROCKET PROPULSION LABORATORY (2)

In September 2013, after two years of development, and a 10- to 12-hour drive from Los Angeles to Black Rock Desert in northern Nevada, some 50 members of the University of Southern California Rocket Propulsion Laboratory (RPL) launched Traveler, their 4-meter tall, 136-kilogram rocket, and held their breaths.

It blew up after 3.5 seconds.

"We were really disappointed, but at the same time glad the rocket launched after two years in limbo and interested to find out what happened," says Jason Silverman, a third-year astronautical engineering student. Turns out, parts of the solid-fuel propellant were improperly cast and started burning too soon, creating excessive pressure.

Despite the setback, these young men and women stand to become the first undergraduate students to design, build, and launch a rocket into space. Their goal is to reach 122 kilometers (space begins at 100 km). They're experimenting with new propellant additives, redesigning the rocket motor, and eyeing a spring launch date.

The dream began in 2005 with RPL's founder, then-undergraduate Ian Whittinghill. Now an aerospace engineer, he is currently the group's industry advisor. Today, the lab is run by Silverman, along with fellow students Jordan Noone and Brandon Edelson. "It was one of the factors that made me want to come to USC," says Silverman.

The lab's mission is to give students experience in all aspects of rocketry, from design to launch. Newbies begin with menial tasks, like sanding (lots of it), and slowly increase their responsibilities according to interest, skill sets, and availability. There are roughly 15 very active members, and another 40 to 50 regular helpers. Silverman, Noone, and Edelson are there daily.

"After a few months, members can learn enough to build their own rockets and get certified by the Tripoli Rocketry Association. This qualifies them to fly bigger rockets and buy propellant," says Silverman.

With the lab completely student-run, the team also learns more earthbound aspects of the job—like Federal Aviation Administration applications for launch approvals. With a university-funded annual budget of US $30 000 to $50 000, RPL relies heavily on industry donations of materials, often tapping lab alumni as liaisons.

"Last year, Boeing gave us a very generous donation of carbon fiber, which we use to make motor cases and fins," says Silverman. "Companies often give us carbon fiber that is too old for them to use but good enough for us."

"Running the lab is quite a bit like running a start-up," adds Noone. "We have to go after our own funds and get our names out to companies."

The Traveler rocket uses 96 kg of an ammonium perchlorate composite propellant, similar to the fuel that was used in the space shuttle's boosters. The fuel is cast in the desired shape of the rocket motor, which takes hundreds of volunteer-hours.

Industry visitors often walk away impressed. Apollo 7 astronaut Walt Cunningham toured the lab before presenting Silverman with the prestigious Astronauts Scholarship Award in October. "It seemed like the students were really in charge of what was going on," says Cunningham. "They'll be well prepared to step out in the world around them and willing to live by those decisions."

For those wanting to start similar labs at their universities, "you'd have a better chance of succeeding if members have done rocketry in the past," Silverman advises. "Our founders already knew what they were doing. We also have good relationships with many aerospace companies." Silverman acknowledges that those were easier to establish because of the concentration of such companies in Southern California.

By this time next year, the students hope to have made history. As Noone wrote in the flight report on the September launch: "We didn't reach our end goal, but...no other group of students has gotten anywhere close.... We had issues, and we'll work through them and will be back soon enough." —**SUSAN KARLIN**

RESOURCES_CAREERS

SHOULD YOU MOVE INTO MECHATRONICS?

RETIRING WORKERS AND MORE COMPLEX CARS CREATE OPPORTUNITIES IN THE AUTO INDUSTRY

UNDER THE HOOD: U.S. automakers need engineers who can work across multiple disciplines, but it's been difficult to attract young talent.

Timing is everything. Five years ago this month, I drafted an article for *IEEE Spectrum* on the need for thousands of new engineers in the U.S. auto industry, as many of its white-collar employees approached retirement.

Then the industry went off a cliff. Years of mismanagement and the severe impact of the Great Recession led to the 2009 bankruptcy and federally backed restructuring of General Motors and Chrysler. The article never ran.

Yet the main point remains valid: More than one in three U.S. auto-industry engineers in 2008 were baby boomers, and during the economic crisis, many of those engineers retired early. Meanwhile, the U.S. industry recovered and resumed hiring, and it hasn't stopped.

The Center for Automotive Research (CAR), a group funded by the automobile industry in Ann Arbor, Mich., said last year that it expected carmakers overall to add 35 000 jobs and suppliers another 44 000. Last July, for example, Ford Motor Co. said it would hire 3000 salaried employees—800 more than planned—of whom four-fifths would be technical professionals in product development, manufacturing, quality assurance, purchasing, and IT.

Many engineers hired into the auto industry will need backgrounds in "mechatronics"—a combination of mechanical, electrical, and software engineering required for the integration of increasingly sophisticated electrical and mechanical equipment found in automobiles. Those skills are "highly sought after, and that talent pool isn't growing," said Mark Roberts, GM's director of talent acquisition for North America, in 2009. And nothing's changed since then, says Kristin Dziczek, director of CAR's industry and labor group.

The most desirable new engineers have hands-on experience building vehicles or subsystems. Historically, Detroit's automakers have hired from engineering competitions like EcoCar2 (or its predecessor, Challenge X), in which students modify a production vehicle to make it environmentally friendlier. Similarly, in the Solar Car Challenge and the Formula SAE competition, student teams design, build, and race lightweight solar-powered cars or single-seat race cars.

But student contestants are a drop in the bucket. As automakers cast a wider net among engineering graduates, they're finding a new reality: "We are not the employer of choice," one company told Dziczek. "This isn't where the action is."

The industry faces a triple whammy, Dziczek says. First, students doubt that auto industry jobs are secure. And for many, Michigan and the Midwest are simply not as appealing as, say, California. Finally, the jobs and challenges themselves aren't seen as exciting.

Detroit's image in particular doesn't help. In the 2000s, a messy sex-and-perjury scandal sent the city's former mayor to jail. The current bankruptcy of the city of Detroit is the latest blow. But recruiters are trying to counter this by underscoring the global nature of the industry, as automakers share platforms and architectures among vehicles built all over the world.

"You may be willing to live in Michigan if you get a chance to work in Australia or China," GM's Roberts pointed out. Today, GM runs engineering and design centers in North America, South America, Europe, China, and South Korea.

Dziczek also sees promise in the allure of cutting-edge automotive technologies. Emerging efforts to build green, connected, and autonomous automobiles pose technical challenges that she believes newly minted engineers find appealing.

Stanford University's efforts in autonomous vehicles, along with Google's self-driving car prototypes, have raised the visibility of auto tech. Global automakers—including BMW, Daimler, Ford, General Motors, Nissan, Toyota, and Volkswagen—have opened and expanded Silicon Valley outposts to scout technologies from outside the auto industry. They are working on the challenges of integrating consumer electronic devices—with a typical 18-month product cycle—into vehicles that must last 15 years or more.

Can Detroit and the U.S. automotive industry drum up its cool factor? Will engineering students buy the argument that automakers offer fun projects? Dziczek says that it will take work—but she's more optimistic today than she was five years ago. —**JOHN VOELCKER**

REFLECTIONS_BY ROBERT W. LUCKY

OPINION

THE RISE, FALL, AND RISE OF ELECTRONICS KITS

Engineering will never outgrow hobbyists

MANY OLDER ENGINEERS FIRST BECAME INTERESTED in electronics through hobbies in their youth–assembling kits, participating in amateur radio, or engaging in other experiments. But I have wondered whether or not students entering engineering today had the benefit of similar experience. • The 1970s and 1980s were great times for electronics hobbyists. Heathkits were hot items, often newer and of better quality than commercial equivalents, featuring the latest hi-fi stereo equipment, for example. I remember poring over the catalog and rationalizing why I had to buy the newest widget. There were two memorable moments associated with each Heathkit–opening the packaged kit, and finally turning on the finished product. In between was kind of messy, but I thought that the world would always be like that: soldering individual components and connecting wires onto circuit boards. • It wasn't to be. Electronics was in a state of rapid transition. Integrated circuits were displacing many individual components, and surface-mount assembly was moving beyond hobbyist capability. Moreover, automated assembly meant commercial products could be manufactured for less than packaging an equivalent kit. By the early 1990s, Heathkit was out of business. • But integrated circuits begat microprocessors, and a new era of hobby electronics began. The Altair computer captured the fascination of many, who now could design and build their own computers. Soon, though, commercial home computers hit the market and lessened the incentives for building your own from scratch. For some years thereafter hobbyists contented themselves mostly with buying board-level components to customize their machines. Nonetheless, it was a heady time, and computer fairs blossomed.

This era faded within about a decade. Commercial PCs came down in price and were bundled with hardware and software at a price that couldn't be beat. Before long we became users, rather than makers. Where, now, was the hobby market to go?

But whenever it seems that there's nothing left for the hobbyist, a new motif arises. In 2006 Eben Upton, at the University of Cambridge, lamented that in recent years new students had very little hands-on experience with electronics. So he started the project that led to the Raspberry Pi computer. This little board is about the size of a smartphone (on which technology it is based). It is bare, inexpensive, and, with all its input/output connections exposed, just begs for experimentation. You can download free operating systems and install them on a standard SD memory card. If you mess something up, just put a new card in.

It is invigorating to see the Raspberry Pi boot up with a Linux command-line interface and a Python programming environment. You can turn it into a Windows-like graphical browser or make it a media server, but that feels like cheating. Instead of duplicating what we already have, this beautiful little board seems destined for more uniquely personal endeavors.

The Raspberry Pi has become a best seller, as has a similar experimental board, the Arduino microcontroller. A great number of sensors, actuators, cameras, and the like have quickly become available for both. Innovative applications abound in such domains as home automation and robotics, and the boards have already formed the basis of several of *IEEE Spectrum*'s Hands On articles. Moreover, we could add to the amateur mix the emergence of 3-D printers, which are still rather a hobby item, though on the cusp of commercialization.

So it seems that now there is much greater capacity for creativity in hobby electronics then there ever was when we were just following the step-by-step soldering involved in building a Heathkit. But I don't want to demean Heathkit, because maybe it will come back after all: In the source code of the company's now minimally revived website is a hidden survey about what kits customers might like. I'm just not betting on it. ■

TERRY PERDUE

HOT OFF THE PRESSES—*TOMORROW'S* PRESSES

NEWS COMES UNEXPECTEDLY, unless it's tech news. Most project information dribbles out over long periods, draining the surprise and delight from the event by the time it occurs. It's like watching a recorded football game when you already know the result. So we at *IEEE Spectrum* have trained our critical eye on the top 10 headlines of the next 12 months. These include a superfast wireless system, Chinese space launches, eerily silent electric race cars, and that recurring chestnut of tech news, the jet pack. By giving you the surprise and the delight now, we allow you to show the proper degree of detachment later on. ▶

ILLUSTRATION BY Carl DeTorres

SMILE, YOU'RE ON "CANDID CAMERA"

OPEN SEASON ON DRONES?

When small civilian drones take to U.S. skies later this year, they'll face pushback—and perhaps a few shotguns

TWO YEARS AGO, THE U.S. Congress mandated that the Federal Aviation Administration integrate robotic aircraft into national airspace by 2015. The FAA has since taken only baby steps toward that goal, but the topic has already sparked much debate–and worry. Initially, the agency, which has been grappling with this issue for the past decade, was focused on avoiding crashes and collisions. But the emphasis has shifted. "In the past year, it's become more about privacy than safety," says Brendan Schulman, special counsel at the law firm Kramer, Levin, Naftalis & Frankel, who is defending a client against the FAA in its first civilian drone case. People just don't want snoopy robots spying on them.

Commentator Charles Krauthammer summed up that sentiment on Fox News in 2012 when he said, "I would predict–I'm not encouraging–but I predict the first guy who uses a Second Amendment weapon to bring a drone down that's been hovering over his house is going to be a folk hero in this country." Don't dismiss such fiery talk as the ravings of a pundit bent on making news. Indeed, there have already been some domestic drone downings: An animal-rights group attempting to document the cruelty of "pigeon shoots" has had a camera-equipped multicopter blown out of the air more than once.

That some shotgun-toting bird hunters would shoot down a small, low-flying drone used to expose their questionable activities might be predictable enough. But those hunters are just the forward guard in a wider campaign meant to signal outrage, typified by the town of Deer Trail, Colo., which has been debating whether to issue drone-hunting licenses.

Something close to these Colorado residents' ire could be heard last year during congressional hearings on the domestic use of drones. Rep. Louis Gohmert (R-Texas) asked the assembled legal and technical experts, "Can you shoot down a drone over your property?" (He got no answer.) In response to all this vigilante fervor, the FAA issued stern warnings against firing at unmanned aircraft.

ILLUSTRATION BY Eddie Guy

FUN FACT: Some shotgun enthusiasts prefer drones to traditional clay pigeons. Catering to this desire, Gnat Shoot provides small drones outfitted with pyrotechnic devices, which adds to the spectacle.

ROBOT SHUTTERBUGS: Camera-equipped multicopters are often the surveillance drone of choice.

A lot of opposition is also being expressed without the threat of 12-gauge antiaircraft fire. For example, public objections caused Seattle's mayor to stop his police department's use of small drones a little less than a year ago. About the same time, Charlottesville, Va., became the first U.S. municipality to pass an antidrone resolution. Then Northampton, Mass., followed suit. Many states have also legislated against drone use in an effort to safeguard privacy.

Northampton's antidrone resolution is especially interesting because it questions the legal basis for extending the FAA's jurisdiction to the very low altitudes where diminutive robotic aircraft typically fly. "Historically, landowners own 'to the heavens,'" says Paul Voss, an engineering professor at Smith College, in Northampton, who helped draft his town's resolution. "There's always been contention about altitudes less than 500 feet, especially close to airports.... All of a sudden, in 2007, the FAA says, 'We own everything down to the grass.'"

Voss is troubled about this for many reasons, including what the FAA's assertion might mean for the expansion of surveillance given that the U.S. Supreme Court has held that citizens should have no expectation of privacy when their activities can be observed from public airspace. "That little thing flying low can capture a lot of stuff–recording conversations, sniffing things, looking into buildings," says Voss. "When all that's public airspace, it's really disturbing."

Ryan Calo, a professor of law at the University of Washington, in Seattle, calls robotic aircraft a "privacy catalyst" because people have responded to them more strongly than to other kinds of surveillance technology. "You can visualize it, unlike what the [National Security Agency] is doing," says Calo. "You get this visceral reaction to drones. Drones are part of a larger disconnect between how quickly surveillance technology evolves and how slowly privacy law does."

Calo would like to see the FAA address privacy concerns as it formulates its new rules, at least as a stopgap measure until lawmakers can pass legislation. Last year Rep. Ted Poe (R-Texas) introduced one such bill, HR 637, which hasn't yet come up for a vote. So the needed laws might be slow in coming. But Calo says people can guard at least some of their privacy in the meantime using existing laws against harassment or "intrusion on seclusion."

Although it will no doubt take more than a year before the United States will get comprehensive regulations for the operation of large, high-flying unmanned aircraft, the FAA should very soon issue notice about the rules governing small systems. The specifics are anyone's guess right now, but when the FAA does make this announcement, two things are for sure: The word *drones* won't appear anywhere in it, because that label is so heavy with connotations of their controversial use by the CIA and the U.S. military overseas; and whatever the new regulations allow or forbid, they will cause this long-simmering issue to boil over.

I would predict–I'm not encouraging–but I predict some enterprising online ammunition dealer will start selling "drone shot" any time now.

—DAVID SCHNEIDER

POST YOUR COMMENTS at http://spectrum.ieee.org/drones0114

TOP: LISA WERNER/ALAMY; BOTTOM: KIKE CALVO/AP PHOTO

ICON BY **Greg Mably**

·HONORABLE MENTION·

BRITS DIAL "M" FOR MONEY

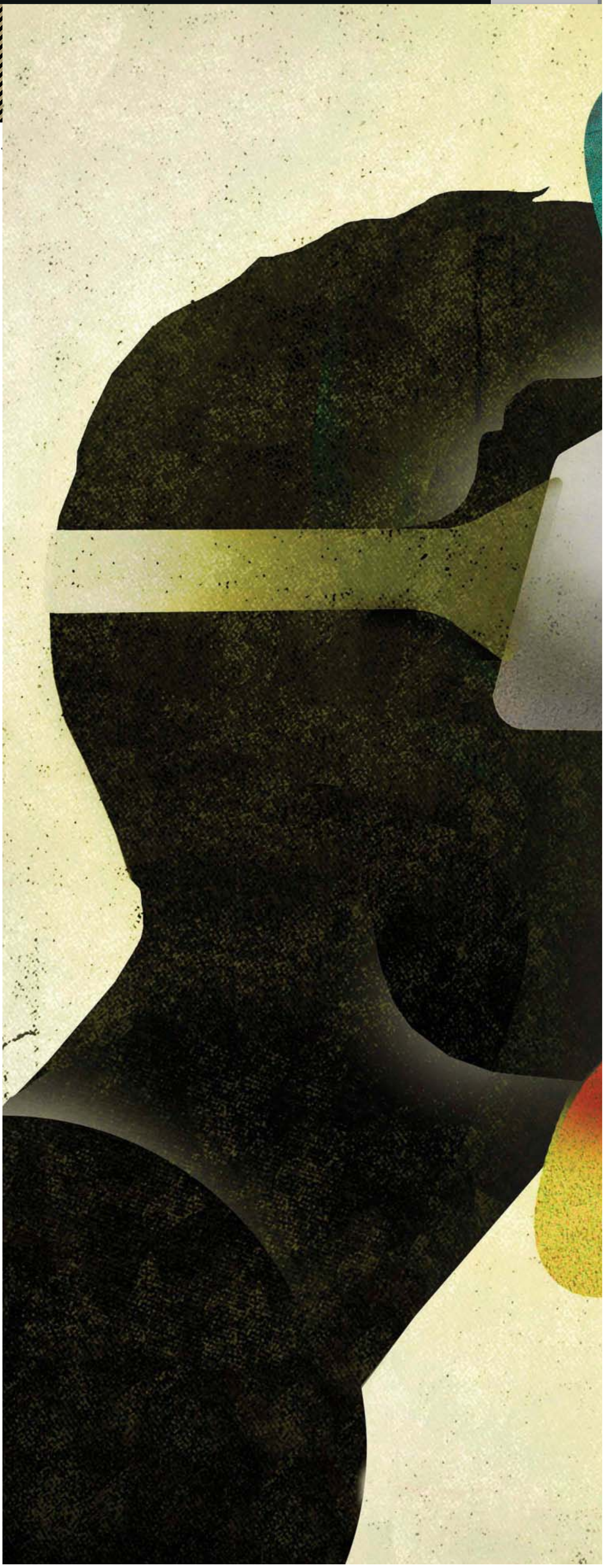
There's now a digital way to provide quid pro quo

THIS YEAR Brits will be able to text money to one another (a trick people have been doing in Africa for years). Under the program, which covers most bank accounts in the country, someone who wants to split the check or bail out a cash-strapped kid at university will need no more than the recipient's mobile phone number. —PHILIP ROSS

IS IT LIVE, OR IS IT VR?

VIRTUAL REALITY'S MOMENT

The Oculus Rift could finally take VR mainstream



VIRTUAL REALITY HAS BEEN hyped as the next big thing for decades–and yet, it never seems to deliver. Despite the potential, particularly in the world of gaming, numerous attempts have left players dizzy with disappointment, and just plain dizzy. So why should you believe us when we say that this is the year?

Two words: Oculus Rift.

The Rift is the brainchild of 21-year-old Palmer Luckey, the founder of Oculus VR, a Silicon Valley start-up in Irvine, Calif. Luckey was weaned on late 20th-century dreams of virtual reality. He'd read about the cyberspace Metaverse in the novel *Snow Crash*, watched Keanu Reeves in *The Matrix*, and seen Jeff Bridges teleport into the world of *Tron*. Coming of age in California during the dot-com boom, he assumed that brilliant geeks were already cooking up a fantastically immersive simulated world. "I grew up imagining it was some technology that people must have in a lab somewhere," he recalls.

ILLUSTRATION BY Brian Stauffer

But although basic virtual reality technology had been around for decades and had been adopted by deep-pocketed entities such as the U.S. military, it still wasn't ready for mass market applications, such as gaming. That wasn't for lack of effort–in the 1990s the once-buzzed-about Virtuality Group put out a series of virtual reality arcade game machines, while Nintendo Co. released the Virtual Boy "console," built around a stereoscopic headset. But chunky displays, expensive hardware, lackluster games, and sluggish processing doomed these attempts.

Today, Luckey's in his own lab at Oculus VR, which has drawn attention for both the people on his team and their progress in creating a high-quality VR headset. The headset–the Oculus Rift–should arrive early in 2014 for around US $300 and will allow third-party game developers to bring their creative skills to bear.

By figuring out how to make the technology both immersive and affordable, Luckey has become the boy wonder of the game biz. He has earned praise from game developers known for being on the bleeding edge of new technologies, such as Valve Corp. (creators of the *Counter-Strike*, *Half-Life*, and *Portal* series) and Epic Games (makers of the *Gears of War* titles). "The folks at Oculus understand the new world order in which we live," says Cliff Bleszinski, the former design director at Epic. "Crowdfunding, community, and hacking are driving many areas of innovation, and they're leveraging that."

In the greatest endorsement, John Carmack, the cocreator of *Doom* and *Quake*–who is considered by many to be the industry's greatest graphics programmer [see "The Wizardry of Id," *IEEE Spectrum*, August 2002]–joined Oculus as chief technology officer in August following the death of original CTO Andrew Scott Reisse in June 2013.

Carmack compares work on the Rift to the early days of Id Software, the company he cofounded in 1991 that repeatedly revolutionized both computer graphics and gaming. (Initially, Carmack split his time and continued to work at Id, but this past November he left to focus on Oculus.) "I have fond memories of the development work that led to a lot of great things in modern gaming–the intensity of the first-person experience, LAN and Internet play, game mods, and so on," Carmack blogged about his new position at Oculus. "Duct-taping a strap and hot-gluing sensors onto Luckey's early prototype Rift and writing the code to drive it ranks right up there. Now is a special time."

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FUN FACT: In 1968, Ivan Sutherland creates the first head-tracking virtual reality display. It's so heavy that it has to be suspended from the ceiling.

The time began for Luckey in 2009, at age 17, when he started tinkering with the head-mounted displays then available. Many of the key challenges in creating virtual reality, he realized, had been solved by the makers of mobile phones and handheld games: Powerful mobile processors, high-fidelity graphics software, and precision motion trackers were all available. The missing link, he thought, was the right optics.

The solution he devised was to build a headset with a single screen and two lenses. The low-cost lenses provided the necessarily wide field of view. Although they introduced some geometric distortion, Luckey knew this could be compensated for with modern graphics hardware. "In the VR heyday in the '90s, computers didn't have that," Luckey says. "This lets Rift be as cheap as it is using parts off the shelf."

By 2011, Luckey was in the perfect place to refine his research: as a head-mounted-display designer at the University of Southern California's Institute for Creative Technologies. The institute is a U.S. Army-funded R&D facility in Los Angeles that uses Hollywood talent to create high-end training and education simulations. Working with the VR pioneer Mark Bolas, Luckey learned the nuances of how people perceive VR environments and began building head-mounted displays. One of them was FOV2GO, a bare-bones project that uses a cardboard mount to hold an iPhone in front of the viewer while rendering a scene.

But his biggest break came early last year when he received an unexpected e-mail from Carmack. The celebrated coder had come across some of Luckey's online postings, and he wanted to know if he could buy one of Luckey's headsets. Carmack had been fascinated by virtual reality since seeing the Holodeck on "Star Trek: The Next Generation" as a teen, and he had been chipping away for decades at the technology needed for VR as he helped create Id's first-person shooter games. Carmack said a decade ago that he considered it a "moral imperative" to create affordable virtual reality for games. Luckey, a huge fan of Carmack's, immediately sent him the only prototype he had. "You're John Carmack," Luckey recalls thinking at the time, "you can get what you want."

Carmack asked if he could demo the prototype to some people, and Luckey agreed. But Luckey had no clue just how many people Carmack had in mind until Carmack presented the Rift at the biggest gaming convention in the country, the Electronic Entertainment Expo (E3), in Los Angeles. One popular game site heralded that the "Rift could be the closest we've come to Star Trek's Holodeck" and another describing it as "a gaming experience with a level of immersion genuinely unlike anything else we have ever encountered."

The positive press didn't just generate interest; it brought in cash. Following the E3 splash, Luckey sought backing on the online fund-raising site Kickstarter, hoping to raise $250 000. Less than two days later, he had more than $1 million (by the time the 30-day funding campaign closed, $2 437 429 had been pledged). "Kickstarter ended up being the only way I could get funded," Luckey says. "When you have a project with no proven market and [with a technology that's] failed so many times in past, it's kind of crazy to go to traditional investors."

Game developers have already been buying Oculus Rift development kits to build titles that will support the Rift. While the larger companies aren't

·HONORABLE MENTION·

TAKE TWO APPS AND CALL ME IN THE MORNING

Prescription-only smartphone apps arrive at the doctor's office

THIS YEAR, patients throughout the United States will begin downloading the world's first doctor-prescribed smartphone app. BlueStar, an app that helps diabetics control their blood sugar, has been cleared by the U.S. Food and Drug Administration, and some insurance companies will reimburse users for its cost. The FDA told the app's developer, the Baltimore-based WellDoc, that a doctor's prescription is necessary because the app doesn't simply track the user's activity, it also recommends actions based on the doctor's treatment plan. —EMILY WALTZ

Read the extended article about this prescription mobile health application on IEEE Spectrum*'s website.*

ICON BY Greg Mably

revealing what they're working on yet, Rift is being publicly embraced by independent developers. Ryan Anderson, a recent college graduate in Goshen, N.Y., is creating a first-person horror game, *Specter Seekers*, for the Rift. Anderson could be making games for the large mobile market, but he sees this as a way of getting in on the ground floor. "There's not much market now," he acknowledges, but "in a few years I think people will be eating this up."

The novelty is also a challenge, though, especially when trying to solve problems that are unique to head-mounted VR displays. For example, "Trying to use head-tracking to get your character to move–that's not something well documented yet," Anderson says. "That's more figuring it out on your own."

NOW AND THEN: The Oculus Rift [top] is the latest in a long line of attempts to make virtual reality commonplace, some of which include Morton Heilig's creation in 1962 of the electromechanical Sensorama [bottom left]; NASA's work in the 1980s on a system that allowed wearers to interact with scenes using data gloves [bottom middle]; and Nintendo's 1995 Virtual Boy [bottom right], which was a spectacular flop.

CLOCKWISE FROM TOP: OCULUS VR; EVAN AMOS; NASA; MARIANE HEILIG

For developers such as Anton Yudinstev, chief executive officer and president of the Russia-based Gaijin Entertainment, coding on the Rift means keeping one eye on the future while still making the most of today's technology. Graphic resolution and precise tracking of the wearer's movements are among the critical challenges, but the most important issue is latency: making the virtual view respond to the players' actions and movements as smoothly as in the real world. In a virtual-reality environment, slow movement is disorienting–even nauseating.

Problems such as those give pause to Lewis Ward, research director for IDC. He notes how earlier enthusiasm over 3-D gaming failed to pan out on platforms such as the PlayStation 3. Home viewers resisted wearing glasses to watch 3-D movies at home, despite the hopes of television manufacturers. "Until those sorts of technology become mainstream, I'm really skeptical that a much larger and more expensive headset will get here," Ward says.

But the smart money is betting that Rift will overcome the factors that doomed those earlier attempts, and that it will do so in time for consumers to play this year. The time simply seems right, to some observers. With the arrival of Google Glass, there's finally "an appetite" for this kind of experience, says analyst Scott Steinberg of TechSavvy Global.

Luckey says the most popular application now available on the Rift developer prototypes isn't a game at all. It's VR Cinema, which puts viewers inside a sort of wraparound theater and lets them watch movies inside the goggles. And if the declining cost of components over the next few years lets Oculus price the headset under $100, Luckey believes that VR entertainment will become ubiquitous. The next step, he says, is reducing the weight and size of the displays. "In the next couple years," he promises, "we'll get to where it will be as light and small as ski goggles."

–DAVID KUSHNER

POST YOUR COMMENTS at http://spectrum.ieee.org/vr0114

MMM, MMM, DATALICIOUS!

4G GETS REAL

LTE-Advanced mobile technologies will bring more network capacity, faster data speeds, and better coverage

HAVE YOU EVER CALLED your cellphone carrier to report poor signal strength? Sure you have. And did that carrier do anything significant to fix the problem? Of course it didn't–unless you live in South Korea.

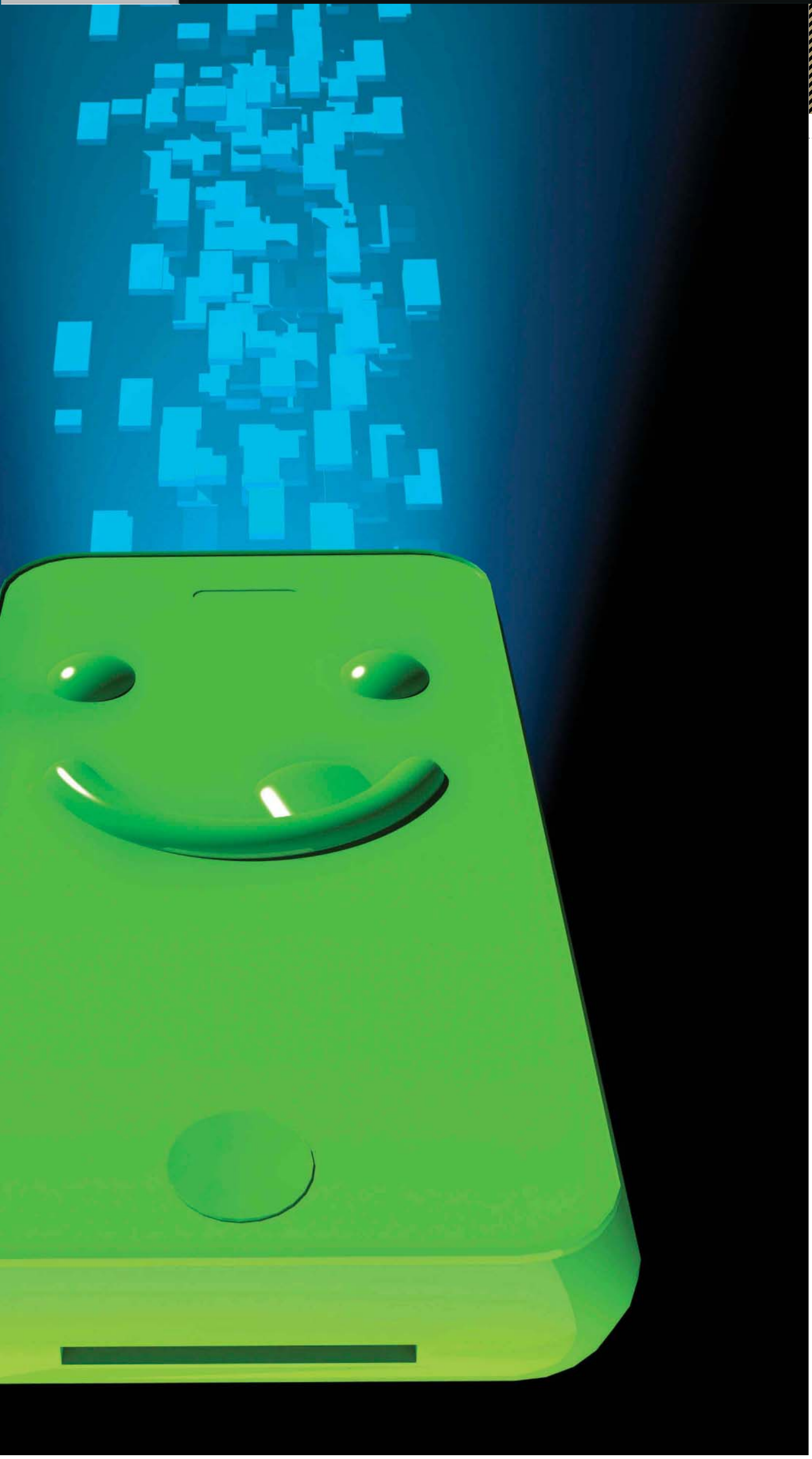
"I guarantee you–if I call my carrier tonight and complain about not getting a good signal in my bathroom, they will send someone to install a repeater first thing tomorrow morning," said Wonil Roh during an interview in Suwon last October.

Full disclosure: Roh heads the Advanced Communications Laboratory at Samsung Electronics Co. But he doesn't need the lofty title to get that kind of attention in South Korea's intensely competitive wireless arena. Home to Samsung and LG Corp., the world's first- and fourth-largest smartphone makers, the country boasts some of the most advanced wireless networks on earth. Last June, for instance, SK Telecom Co. launched what it called the "world's first publicly available LTE-Advanced network." Short for Long Term Evolution, LTE is the globally embraced standard behind today's top-of-the-line 4G smartphones and tablets. For the same price as an LTE plan, LTE-Advanced subscribers could now get twice the data rates, SK claimed. Not to be outdone, its competitors LG Uplus Corp. and KT Corp. began offering their own LTE-Advanced services in July. By October, a million people had signed up for SK's service alone.

What's happening in South Korea will soon come to pass in other parts of the world. Operators everywhere face a universal and unremitting predicament: Customers want more data at faster speeds to run ever more sophisticated applications. Today it's video calls and sports broadcasts; tomorrow it'll be telemedicine and virtual shopping sprees. Each year, according to Cisco Systems, global mobile traffic more than doubles. And that exponential growth is showing no signs of waning.

So now, four years after the first networks using LTE went live, operators are looking to its successor. Already, more than a dozen carriers outside of South Korea, including AT&T, Australia's Telstra, Japan's

ILLUSTRATION BY Eddie Guy



NTT DoCoMo, and Telenor Sweden have reported that they are testing LTE-Advanced technologies, and analysts expect commercial rollouts to start this year. By 2018, according to ABI Research, global LTE-Advanced connections will approach 500 million–about five times as many as LTE can claim today.

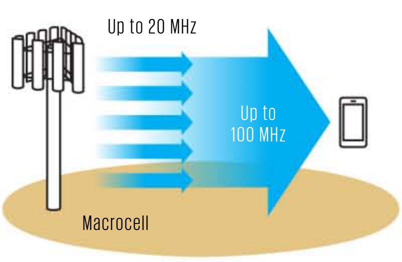
"There's no way around it–LTE has to evolve," says Lingjia Liu, a wireless expert at the University of Kansas. "LTE-Advanced will become the dominant standard."

WIRELESS SPECIALISTS are calling LTE-Advanced "true 4G" because unlike ordinary 4G LTE, it actually meets the International Telecommunication Union's specifications for fourth-generation wireless systems.

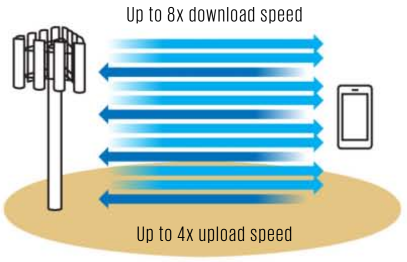
One of these criteria is speed. LTE-Advanced can theoretically achieve data download rates as high as 3 gigabits per second and upload rates as high as 1.5 Gb/s. By comparison, LTE tops out around 300 Mb/s for downloads and 75 Mb/s for uploads. And LTE-Advanced isn't just about faster rates. It also includes new transmission protocols and multiple-antenna schemes that enable smoother handoffs between cells, increase throughput at cell edges, and stuff more bits per second into each hertz of spectrum. The result will be higher network capacity,

THE LTE-ADVANCED ADVANTAGE

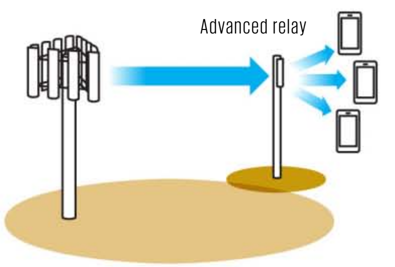
Known as "true 4G," LTE-Advanced includes a menu of wireless technologies that will boost the capacity of current 4G LTE networks and make possible mobile download rates as high as 3 gigabits per second. Here are five key features that distinguish the new standard from its predecessors.



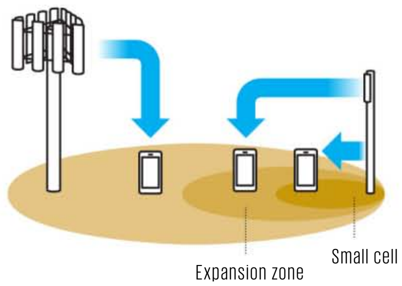
WIDER BANDWIDTH
Using a technology called **carrier aggregation**, operators can combine up to five LTE frequency channels, or carriers, as wide as 20 megahertz that reside in different parts of the radio spectrum.



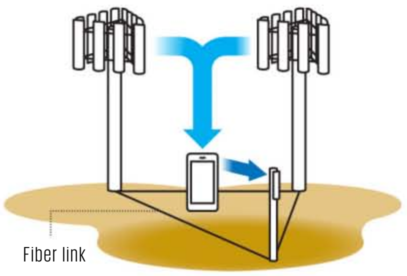
MORE DATA STREAMS
LTE-Advanced supports more sophisticated **multiple input, multiple output** (MIMO) techniques, which enable several antennas to send and receive data. One use of MIMO, called spatial multiplexing, separates transmissions into many parallel streams, increasing data rates in proportion to the number of antennas used.



SMARTER RELAYS
Conventional radio repeaters, such as those used in LTE networks, simply amplify transmissions from a base station. LTE-Advanced allows for more **advanced relays**, which first decode the signals and then forward only those meant for nearby users, increasing the total number each relay can serve.



SUPPORT FOR SMALL CELLS
A protocol called **enhanced inter-cell interference coordination** (eICIC) alleviates interference to a small cell—a low-power base station whose coverage zone lies inside a traditional macrocell. The two cells can dynamically coordinate their use of spectrum, letting the small cell expand its transmission range.



COORDINATED TRANSMISSIONS
To improve reception, LTE-Advanced introduces **coordinated multipoint** (CoMP). It permits several base stations to form a single cell, allowing a mobile unit to connect with all of them at the same time. For example, the unit could receive downloads from high-power towers while uploading to a nearby small cell.

more consistent connections, and cheaper data.

As its name implies, LTE-Advanced is meant to enhance LTE. The two standards are mutually compatible, which is great for consumers. New LTE-Advanced phones will still work on LTE networks, and old LTE phones will connect to LTE-Advanced networks. Operators will benefit as well. Those wishing to upgrade to LTE-Advanced won't need to scrape together new radio spectrum or build out new infrastructure as they did to make the leap from 3G to LTE.

But here's the catch: Carriers won't roll out all of LTE-Advanced's capabilities at once. Like LTE before it, the new standard isn't a single technology but rather a grab bag of many technologies, and operators will pick and choose items as they're needed. For instance, the South Korean telcos that now claim to have LTE-Advanced networks are really talking about just one of LTE-Advanced's capabilities, known as **carrier aggregation**.

This feature increases the bandwidth available to a mobile device by stitching together frequency channels, or carriers, that reside in different parts of the radio spectrum. Ordinary LTE can deliver data using a contiguous block of frequencies up to 20 megahertz wide. But as more and more companies and devices vie for radio spectrum, such wide swaths are increasingly scarce. Most operators, having bought bits and pieces of spectrum wherever they could, have fragmented collections.

Carrier aggregation solves that problem. It allows operators to combine their narrow, disjointed channels

ILLUSTRATION BY James Provost

into "one very big pipe," says Sang-min Lee, a senior manager at SK's R&D center in Seoul. To deliver its LTE-Advanced service, for example, the company combined two separate 10-MHz-wide channels, at 800 MHz and 1.8 gigahertz, into a single 20-MHz-wide channel, essentially doubling the data rate available to each user.

"We can get a huge performance gain," Lee says, pointing out that a connection on SK's new network can support downloads up to 150 Mb/s versus the maximum 75 Mb/s available through its LTE service. The LTE-Advanced standard allows operators to combine up to five carriers as wide as 20 MHz each for a maximum bandwidth of 100 MHz—five times as much bandwidth as conventional LTE offers.

Following SK's lead, most early LTE-Advanced adopters will likely focus on carrier aggregation because the higher data rates are an easy sell. "From a marketing standpoint, it's a slam dunk," says Peter Jarich at Current Analysis, in Washington, D.C. But, he adds, that's just the beginning. To keep their networks running smoothly, operators will need to reach deeper into the LTE-Advanced toolbox.

BESIDES CARRIER AGGREGAtion, four other key features distinguish LTE-Advanced from its predecessors. The first of these is called **multiple input, multiple output** (MIMO), which allows base stations and mobile units to send and receive data using multiple antennas. LTE already supports some MIMO, but only for the download stream. And it limits the number of antennas to four transmitters in the base station and four receivers in the handset. LTE-Advanced allows for up to eight antenna pairs for the download link and up to four pairs for the upload link.

MIMO serves two functions. In noisy radio environments—such as at the edge of a cell or inside a moving vehicle—the multiple transmitters and receivers work together to focus the radio signals in one particular direction. This "beamforming" boosts the strength of the received signal without upping transmission power.

If signals are strong and noise is low, however—such as when stationary users are close to a base station—MIMO can be used to increase data rates, or the number of users, for a given amount of spectrum. The technique, called spatial multiplexing, permits multiple data streams to travel over the same frequencies at the same time. A base station with eight transmitters, for instance, can send eight streams simultaneously to a smartphone with eight receivers. Because each stream arrives at each receiver at a slightly different angle, strength, and time, processing algorithms in the smartphone can combine these inputs and use the differences to sort out the original streams.

As a rule of thumb, spatial multiplexing can multiply data rates proportionately to the number of antenna pairs available. So under the best circumstances, eight pairs could increase data rates roughly eightfold.

Another important LTE-Advanced technology is relaying, which extends coverage to places where reception is poor. Wireless network architects have long used relays to extend a tower's reach, such as into a train tunnel or a remote area. But traditional relays, or repeaters, are relatively simple. They receive signals, amplify them, and then retransmit them.

LTE-Advanced supports more **advanced relays**, which first decode the transmissions and then forward only those destined for the mobile units that each relay is serving. This scheme reduces interference and lets more

FUN FACT: In South Korea, LTE-Advanced subscribers can download an 800-megabit movie in as little as 43 seconds.

·HONORABLE MENTION·

BUGATTI'S DREAM FINALLY TAKES FLIGHT

The famed race car designer's ill-fated plane gets a second chance

ETTORE BUGATTI was known for his elegant race cars of the 1920s and '30s. Few people realize that he also designed an elegant—and extraordinarily innovative—airplane. That's because World War II interrupted its construction, and the aircraft never flew. But a copy of it will be completed this year. Be on the lookout for Bugatti's Blue Dream to finally take to the air. —DAVID SCHNEIDER

ICON BY Greg Mably

users link with the relay. LTE-Advanced also allows a relay to communicate with the base station and with devices using the same spectrum and protocols as the base station itself. This has the advantage of letting regular LTE handsets connect to the relay as if it were a traditional tower. The relay avoids interfering with the base station by scheduling its transmissions during certain times when the base station is silent.

Yet another principal LTE-Advanced tool will help alleviate network congestion. Known as **enhanced inter-cell interference coordination**, or eICIC, it will be used for so-called heterogeneous networks, in which low-power base stations, or small cells, overlay the "macro" network of traditional towers. Many carriers have already begun using variously sized small cells (also called metro-, micro-, pico-, or femtocells) to expand data capacity in busy urban centers. These compact boxes are cheaper, less obtrusive, and easier to install, and analysts see a bright future for them. But as operators cram more and more cells into the same spaces, they will have to find ways to lessen the inevitable crosstalk.

The eICIC protocol builds on the LTE protocol ICIC, which helps reduce interference between two macrocells. Using ICIC, a base station can reduce its transmission power at certain frequencies at certain times when a neighboring station is using those resources to talk to mobile users near the edge of its coverage area. But this spectrum-sharing scheme works only for delivering data streams. To communicate with a mobile device and help it make sense of the data, a base station must also send control signals, which carry housekeeping information such as scheduling decisions, retransmission requests, and decoding instructions. And because the device expects these messages to arrive on predictable frequencies at predictable times, the base station can't simply lend those resources to a neighbor whenever it needs them. LTE resolves this predicament by making control signals robust enough to withstand relatively high amounts of interference.

Small cells, however, make things more complex. For some devices trying to link with a small cell, which sits inside a macrocell, control signals from the macro tower can overwhelm the signals from the small cell. The eICIC protocol handles this scenario in one of two ways. If the network is using carrier aggregation to combine two or more different frequency channels, the macrocell and small cell can simply use separate channels to send control signals. Meanwhile, both cells use all the channels to deliver data so that mobile users still benefit from the combined bandwidth. The two cells share this spectrum, as with ICIC, by coordinating

CONTINUED ON PAGE 54

FUN FACT: The wireless industry is preparing for 1000 times as much mobile data traffic within the next decade.

·HONORABLE MENTION·

GAMES GOOGLE PLAYS

Will the search giant launch a game console this year?

GOOGLE HAS struggled for years to become a major force in hardware, but it doesn't take a marketing genius to see how a game console could expand the already immense reach of Google's Android operating system.

Buzz started after a *Wall Street Journal* story reported last June that the company is working on a game machine along with a smart watch. A spokesman for Google declined to comment on the rumors, but he noted the company's May release of Google Play, a cross-platform game service and software development platform. "By building off of what Google is good at—mobile and cloud services—these game services help power great gaming experiences for users," the spokesman says. If Google does enter the market, it will face stiff competition from Microsoft's and Sony's latest game systems—and possibly even from another company that's rumored to be considering a move into the console market: Apple. —DAVID KUSHNER

ICON BY Greg Mably

GENTLEMEN, START YOUR, UH, MOTORS

THE FAST AND THE FORMULA E

High-wattage EV cars will race in cities around the world

IMAGINE 20 STATE-OF-THE-art single-seat racing cars, lined up in front of grandstands and TV cameras. Envision them streaming past some of the world's best-known urban landmarks: the Brandenburg Gate, Big Ben, Miami's South Beach. Consider the breathtaking acceleration, the heart-stopping braking, the daredevil overtaking maneuvers. Think of the scream of engines and the tang of fuel at the back of your nose.

Now lose the scream and the tang. This is Formula E, the first automobile racing series based completely on electric cars.

Starting in September, Formula E will run on street circuits in 10 cities around the world, showcasing the capabilities of electric cars and helping to burnish their "worthy, but rather dull" image, as Paul Drayson puts it. He's the scientific consultant to series promoter Formula E Holdings (FEH) and the team principal of Drayson Racing, the British team that was the first to sign up for the series. "For me, the most important thing is that it can make technology really cool and exciting," he says.

And that is why the races will be held on city street circuits, rather than at dedicated racetracks, adds FEH chief executive Alejandro Agag. "Electric cars are for cities; that's their natural habitat, if you like," he says. "It's where the technology makes the most sense, and that's where we need to show them off."

Half the point of Formula E is to accelerate the development of electric drivetrains so that teams will eventually be free to choose any configuration and design of electric motors, batteries, and charging systems. But to get the series moving, this year all teams must use the same car, developed by Spark Racing Technologies, in Burgundy, France.

The car has a monocoque chassis and bodywork from Dallara Automobili, in Parma, Italy; lithium-ion batteries from Williams Advanced Engineering, near London; and a four-speed sequential gearbox (common in race cars, it lets you shift gears without a clutch) from Hewland Engineering, near Oxford, England.

That gearbox will relay power to the wheels via an electronic control unit from McLaren Automotive, the British supercar specialist.

ILLUSTRATION BY Brian Stauffer

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FUN FACTS: Ordinary car noise: 70 decibels; bus: 90 dB; Formula E: 80 dB; Formula One: 150 dB

THE GREEN GUTS of this year's Formula E cars all come from McLaren Automotive.

In fact, it's the same system McLaren supplies to all the cars in the U.S. Indycar series, although here it will run different software. The electrical traction systems run at 800 volts, generating enormous amounts of heat. It is channeled away from the cars via water cooling and lightweight heat sinks, says Peter van Manen, managing director of McLaren Electronic Systems.

A Formula E race will last about an hour, with 10 teams each fielding two drivers. The cars will generally be allowed to use no more than 134 kilowatts of power (180 horsepower). A certain number of times in the race, however, they will be permitted to boost to 200 kW, reaching speeds of up to 220 kilometers per hour (137 miles per hour).

The cars will race until their batteries are exhausted–about 20 minutes. And then you'll see by far the strangest thing about this race: Rather than swap out the batteries, the drivers will swap cars. Each driver will get out, run 100 meters down the pit lane to the team's garage, jump into the fully charged spare car and race for another 20 minutes while the first car recharges. Then the driver will make another pit stop, run to the first car, and complete the race. Power management will therefore be a paramount skill, as it was in the early days of flight.

Inductive battery charging across an air gap, via coils embedded in the road, would eliminate the need for car swapping and allow for lighter batteries. Indeed, FEH has plans to use such a system, developed by HaloIPT, a New Zealand company acquired two years ago by the cellphone firm Qualcomm. This year, though, the inductive charging will be static, with just one pad on the ground, and it will be used only for a safety car, which is sent out in front of the other cars to limit their speed.

Another rule for this year only: Each car will run on a single electric motor developed from the unit McLaren designed for its latest street car, the P1 hybrid. Weighing just 26 kilograms, the motor spins at 17 500 rpm, similar to the revs of a Formula One V8, and develops 200 kW. That gives a power-to-weight ratio of 7.7 watts per gram, the highest of any automotive power plant in the world, says van Manen. And although Formula E cars are slower than Formula One cars, they'll achieve far greater acceleration because of the instant availability of full torque with electric propulsion. The cars have also been designed to generate current for the battery during braking.

The series will start in Beijing on 20 September and continue on to Putrajaya, Malaysia; Hong Kong; Punta Del Este, Uruguay; and Buenos Aires before reaching Los Angeles on 14 February 2015 and Miami on 18 April. Then comes Monte Carlo, Berlin, and London, where the series will finish on 27 June.

So will Formula E be the spectacle that the organizers hope for? Well, shutting down the center of a city does tend to attract attention. But one complaint is that the experience of motor sports is so tied up with that sensory overload of noise and odor that the quiet of an electric motor will render it sterile. Still, that hasn't stopped audiences from thrilling to the instant acceleration of electric motorcycle racing, which has had its own TTXGP racing series since 2009.

Besides, electric cars have a noise all their own. It's the sound of the future.
—STUART NATHAN

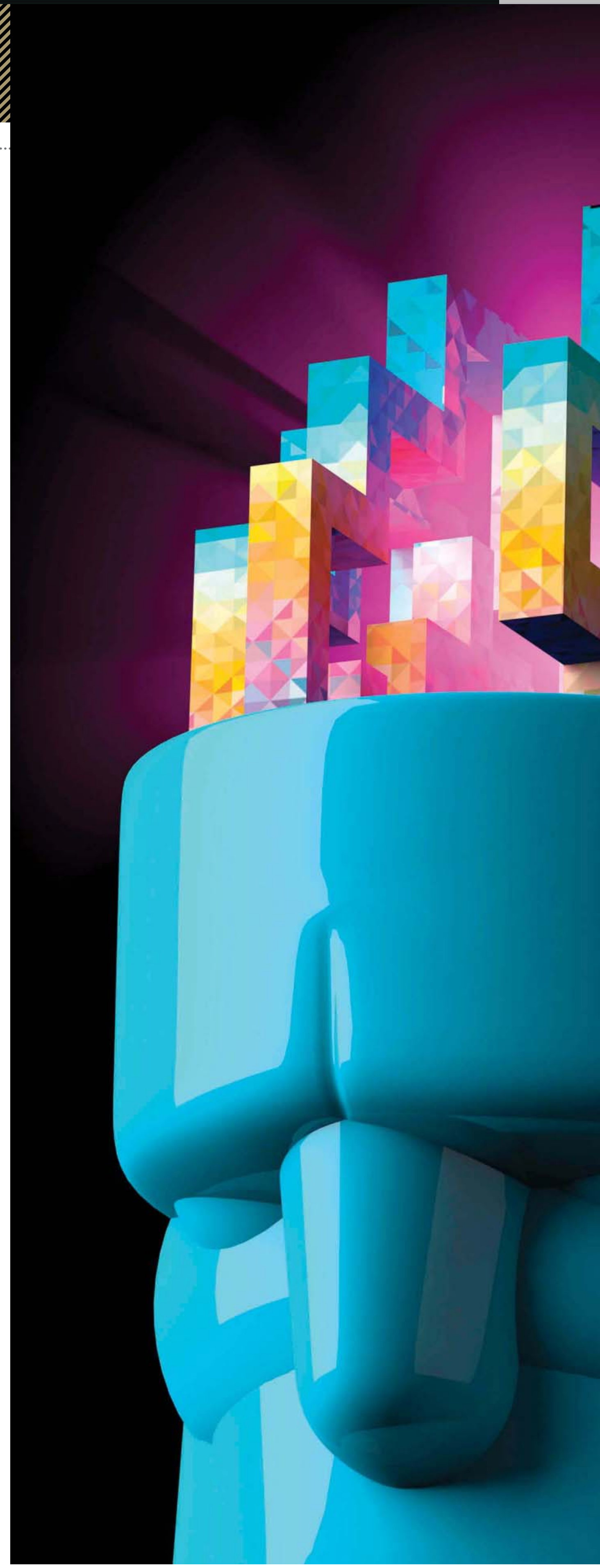

ILLUSTRATION BY **Eddie Guy**

NAVIGATING YOUR NOGGIN

BIG SCIENCE TAKES ON THE BRAIN

A massive U.S. initiative will explore the mind's mysteries

5

SOMETIMES WHEN I THINK of the human brain, the theme from "Star Trek" starts playing in my own head. It's the music of great unknowns–and in certain ways the human brain, with more connections between its cells than there are galaxies in the observable universe, is as vast and uncharted as that final frontier.

Despite decades of research, no detailed explanation yet exists of how the interplay of electrical and chemical activity between cells becomes the music I hear in my mind's ear. No scientific model describes how a few simple notes elicit such emotion, nor how I might protect those feelings from dementia's ravages decades hence.

Beginning to answer such questions is the grand, daunting ambition of the Brain Research Through Advancing Innovative Neurotechnologies program, better known as the BRAIN Initiative. U.S. president Barack Obama

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formally announced the federal project in April 2013 with a US $110 million first-year budget that will be parceled out to the National Institutes of Health (NIH), the National Science Foundation (NSF), and the Defense Advanced Research Projects Agency (DARPA). Four private institutions–the Kavli Foundation, Allen Institute for Brain Science, Howard Hughes Medical Institute, and Salk Institute for Biological Studies–have also committed a total of $122 million of their own money to BRAIN work in 2014. Over the next year, the BRAIN Initiative should coalesce into one of the century's defining scientific projects.

"In my mind, it's the greatest challenge of our time," says Miyoung Chun, the Kavli Foundation's vice president of science programs. It was Chun who, in late 2012, played matchmaker between the White House and a small group of neuroscientists who had big plans for charting neurological activity. From those meetings grew the BRAIN Initiative, which at its inception focused narrowly on developing new tools to record electrical activity in unprecedented numbers of neurons, with the plan to eventually turn those recordings into maps of human brain function.

With those maps, scientists might come to know far more than they do now about the brain's biology, what happens as people think and feel, or when malfunction becomes disease. They're not the first researchers to seek this knowledge, of course, but the project's proponents say we're at a unique historical moment: Our technological and computational power may finally be commensurate with our questions.

"The human brain is a miracle. It gives rise to infinitely many thoughts, emotions, memories, actions. How can one biological organ, a collection of cells, do all that?" says Rockefeller University neuroscientist Cori Bargmann, cochair of the NIH's advisory committee. "No matter how long you've been a neuroscientist, it is still amazing that this complexity emerges from such mundane biological components."

WHEN PRESIDENT OBAMA first announced the BRAIN Initiative, however, many researchers were skeptical. The current tools of human brain analysis are indeed coarse, they agreed, incapable of recording neurological activity at the detail and scope they'd like. But was large-scale, fine-grained mapping realistic? For instance, current state-of-the-art neurological recording of zebra fish involves some 80 000 neurons, and that requires subjecting the creatures to techniques that would never be used on humans. That's quite a few orders of magnitude less challenging than recording activity from the 75 million neurons of a mouse, to say nothing of a human's roughly 86 billion neurons.

Even if technologies could be developed to record all that information, what could you do with the results? It would be an informational deluge that would make genomic big data look puny. "Many people were concerned that the project was overambitious and impractical," says Donald Stein, a neurophysiologist at Emory University, in Atlanta.

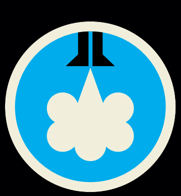
Following the scientific outcry, the NIH, NSF, and DARPA held a series of workshops and meetings with scores of scientists to discuss what BRAIN should be. While the project will continue to evolve, the research priorities described in recent NSF and NIH reports emphasize basic science and tool development that can lead to grander map-making projects as the years go on.

The report from the NIH advisory committee doesn't put the recording of cell activity at the top of the list. Rather, it starts with a back-to-basics mandate. The report calls for a census of the brain's cell types, which encompass not only many varieties of neurons but also glia, a long-underappreciated family of cells that may actually outnumber neurons. The physical forms of these cells

·HONORABLE MENTION·

JET ME OUT OF HERE

At last, we'll have personal vertical transportation



THIS YEAR, half a century after James Bond first flew one, Martin Aircraft Co., of Christchurch, New Zealand, will begin selling a jet pack, of sorts: It uses not jets but rather a pair of ducted fans. It can fly 30 kilometers and is tentatively priced at US $250 000 (for armies) or $150 000 (for emergency rescue services). A consumer version will take a bit longer to get regulators' approval. —PHILIP ROSS

ICON BY Greg Mably

PREVIOUS PAGES, TOP LEFT: FIA

in mice and other animals will be characterized, along with their molecular and genetic properties, their locations, and ultimately how they connect to other cells, both individually and in groups.

These network-spanning wiring diagrams are called connectomes, and they're considered crucial. Researchers now understand that an act of perception or cognition doesn't rely on the neurons in just one area of the brain; instead, it involves complicated neural circuits that can weave through multiple regions. Although similar connection-mapping projects already exist–the first roundworm connectome was published in 1986, and the NIH's Human Connectome Project launched in 2009–they don't approach the comprehensiveness or detail envisioned in the NIH report.

To study cells and their networks in new detail, investigators will need to rely on a whole new toolbox, possibly including microscopes that can look at larger sections of a brain than is now practical, and "optical needles" that can penetrate a brain's deep tissues, rather than just the outermost layers where most imaging now occurs. Going beyond passive imaging, some new methods enable researchers to activate cells or whole networks inside a living animal, helping them

FUN FACTS:

150 TRILLION Estimated number of connections that link the neurons in the human brain

160 MILLI-SECONDS Human response time to an auditory stimulus

750 MILLILITERS PER MINUTE Typical blood flow through the human brain (15 percent of cardiac output)

250 000 NEURONS PER MINUTE Approximate rate of neuron creation during early pregnancy

8–10 SECONDS Time until unconsciousness after loss of blood supply to the brain

1.5 KILOGRAMS (3 POUNDS) Average weight of an adult brain (about 2 percent of the body's weight)

understand cell roles and network dynamics and eventually linking them to behavior. Optogenetic techniques, for example, deliver light-sensitive molecules to target cells, then stimulate them with light pulsed through a fiber-optic implant.

The BRAIN Initiative hasn't given up on its original goal of recording neuronal activity, which will also require new tools. One proposed method would make use of flexible sheets fashioned from hundreds of thousands of nanowire electrodes, which would conform to a brain's topography while noninvasively recording its activity. Researchers continue to debate how much to record: Eavesdropping on every single cell in a nervous system isn't feasible, but how many are representative?

As of now, activity can be directly recorded from perhaps 100 neurons at a time, their electrical spikes measured by tiny implanted electrodes. At the other end of the spectrum is functional magnetic resonance imaging, or fMRI, which measures blood flow as a proxy for activity in regions containing millions of cells. "There's a lot of information in the middle scale that we don't have," says Jack Gallant, a neuroscientist at the University of California, Berkeley. "And it's not just that you need to record from every neuron. You need to record for a long period of time."

Measuring that activity over time is the only way to study the extraordinary dynamism of brains. There's no such thing as a static map of a brain. Its connections are ever-fluctuating, reconfiguring themselves on the fly. We now know that the connectome is capable of extreme transformation, as seen in the brains of stroke victims who recover functions typically linked to now-damaged regions.

Dealing with the resulting data will require still more tools, of the mathematical and conceptual varieties. Researchers will need algorithms and processing techniques that allow them to make sense of raw data and to understand how neurological activity encodes information, just as computer codes are so much more than strings of ones and zeros. "There are certain kinds of data that we get from the brain and don't know how to analyze," says Gallant. "Nonlinear systems with feedback"–weather, for example, or brains–"are mathematically hard systems to deal with. There just aren't good tools for dealing with them."

WHEN THE NIH ISSUES ITS first BRAIN grants in 2014, it will likely concentrate on projects that match the agency's strengths, such as direct work on animals. Once the NIH's concentrations are clear, the NSF will start doling out its funds, perhaps focusing on its own strengths, such as biophysics and computer

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FLY ME TO THE MOON

THE NEXT SPACE SUPER-POWER

A lunar rover, a crewed space station, and new rockets top China's space agenda

FOR THE OPENING CEREMONY of the 64th International Astronautical Congress in Beijing this past September, the Chinese hosts pulled out all the stops. Acrobats bounded against a backdrop of starry skies, dancers in bulky spacesuits lumbered across the stage, and opera singers sang songs of love under a glowing neon moon.

Throughout the weeklong conference, Chinese officials spoke proudly of developing their lunar exploration program, building a heavy-lift rocket, constructing a spaceport, and planning an orbital space station. As 2014 dawns, China has the most active and ambitious space program in the world.

"They are having launches, and in the United States we're in gridlock," says Joan Johnson-Freese, a professor at the U.S. Naval War College, in Newport, R.I. "The Chinese will have a rover on the moon, and we're still developing PowerPoints for programs that don't get approved by Congress."

That rover should be rolling over the regolith right now, if the mission has gone according to plan.

How are the Chinese accomplishing so much? One explanation came from Gao Hongwei, chairman of the state-owned China Aerospace Science & Industry Corp., who took the stage during September's Beijing conference. "We are developing a space industry with Chinese characteristics," he said.

Johnson-Freese put it more bluntly: "In terms of technology, are the Chinese at a peer level or more advanced than us? No, absolutely not. What they have that we don't is political will."

That point was driven home in a panel discussion at the Beijing conference, where the heads of the world's major space agencies took the stage together. When asked about his agency's biggest challenge, Ma Xingrui, director of the China National Space Administration, spoke of engineering complications with the heavy-lift rocket now in development, a behemoth that will be capable of lifting 25 tons into orbit. When Charles F. Bolden Jr., the NASA administrator, was asked the same question, he had quite a different answer. "I think NASA's biggest challenge is inspiring our nation," he said. "We need to inspire the American public, and we need to inspire this Congress. Because that translates to funding."

CHINA'S SPACE PROGRAM differs from those of other nations in part because of the nation's political structure: A single-party government with a bevy of strong state-owned enterprises can get a lot done. And the Chinese government has committed fully to its space program, seeing it as a way to win global prestige. While China is just now meeting milestones that the United States and the former Soviet Union passed decades ago, the Chinese government's unflagging support means that its program is quickly catching up.

China launched its first orbital space lab, a small module called Tiangong-1 (the name means "heavenly palace"), in 2011. There followed a cautious series of spacecraft rendezvous: An uncrewed craft docked that year, and there was one crewed mission in both 2012 and 2013, with short stays aboard the lab. The next step will be the launch of Tiangong-2, another space lab, in 2015, followed by the construction of a full-scale space station, due for completion around 2020.

This slow and steady approach, so unlike the U.S.-Soviet space race, means that Chinese astronauts "spend a lot of time on the ground," says Brian Harvey,

ILLUSTRATION BY Brian Stauffer

FUN FACT: Liu Yang, China's first female astronaut, performed a 3-minute tai chi routine during her 2012 visit to China's Tiangong-1 space lab.

author of the recent book *China in Space*. "They are very disciplined in not letting themselves be rushed. China is very conscious of its history. They've been doing rocketry since 1274, so what's the hurry?"

The Chinese expect to finish their space station around the time that the International Space Station runs out of funding, and they hope to fill the void. Already the Chinese government has spoken of allowing other nations' astronauts to stay aboard the station. China also intends the station to facilitate even more ambitious voyages into the solar system.

"The Chinese have said repeatedly that they are not going to go into space, land on the moon, look around, say, 'Been there, done that,' and consider themselves done," says Johnson-Freese. "They're going to do stepping-stone infrastructure, and in those terms their space station makes sense."

Where else might Chinese astronauts go? Their current program doesn't commit to a crewed mission to the moon, but many experts believe the odds favor one. A recent report published by the Chinese Academy of Sciences proposes a road map that also mentions a crewed lunar base, a crewed mission to Mars, and robotic exploration of other planets by the year 2050.

That report lists technologies that Chinese researchers need to master, including autonomous navigation and high-speed communication systems for deep space, as well as fuel cells and atomic generators to power the spacecraft. Activity on all these engineering fronts could indeed achieve the report's stated goal, says Harvey: "By 2050, China should be the leading scientific nation in the world."

HAINAN ISLAND, WHICH LIES south of Hong Kong in the South China Sea, is the site of one of the world's biggest construction projects. Workers are pouring concrete near the town of Wenchang for China's fourth space-launch facility, designed to accommodate the next-generation Long March 5 heavy-lift rockets. These rockets are too big to move to China's other three launch sites—they don't fit through the railway tunnels—so workers are building the large-diameter rockets in the harbor city of Tianjin, and then transporting them by barge to Hainan.

The Hainan site is expected to be operational by the end of 2014, when it will begin launching midsize rockets; the Long March 5 is scheduled for completion in 2015. What's more, tourists will be able to take in the show. The Chinese space agency is building resorts and a space theme park on the island, which will reportedly include an aerospace museum and spaceflight simulators. Chinese space enthusiasts will be able to take a holiday in Hainan and, presumably, enjoy the spectacle of their own rockets soaring into the stratosphere.

China's rockets aren't just getting bigger; they're getting better chemistry. The first few Long March rockets used highly toxic and corrosive rocket fuels, but the newest multistage rockets use clean and powerful liquid propellants (kerosene and liquid oxygen for the first stage, hydrogen and liquid oxygen for the upper stage). "In five years' time, China will have a completely new rocket fleet," says Harvey.

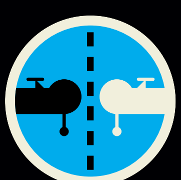
The crewed space program may get most of the attention, but China's new rockets won't be used only to launch space labs and astronauts. Just as the Chinese space station will provide an alternative (or a successor) to the ISS, China is seeking to furnish the world with an alternative to today's two global satellite navigation systems: GPS, run by the United States, and Russia's GLONASS.

China's BeiDou Navigation Satellite System already has 14 satellites in orbit, according to a presentation at the International Astronautical Congress by Ran Chengqi, director of the China Satellite Navigation Office. In December 2012 the system began providing regional service for the Asia Pacific, with coverage stretching from China to Australia. Ran announced that more than 20 vehicle manufacturers have already begun installing dual-mode navigation systems

·HONORABLE MENTION·

NASA'S ARTFUL DODGERS

A contest tests drones' ability not to run into one another



ROBOTIC AIRCRAFT from all around the United States will compete later this year near Edinburgh, Ind., to determine which can best sense other craft and avoid colliding with them. NASA is putting up a US $500 000 prize and plans a more challenging contest in 2015, for a prize of $1 million. —PHILIP ROSS

ICON BY Greg Mably

that use both GPS and BeiDou. "We have entered an era of multinavigation system integration," said Ran, "and compatibility and interoperability have become the major trends." By 2020, the full fleet of 35 satellites is expected to be in place, providing global coverage.

Finally, China is turning its attention to space science, which has been largely missing from its space program thus far. In 2010 the Chinese government established a special budget to support five space science satellites, according to Wu Ji, director general of space science at the Chinese Academy of Sciences. The first of these satellites, the Hard X-ray Modulation Telescope, will perform all-sky surveys and in-depth observations of X-ray sources like black holes and neutron stars. It's expected to launch in 2014 or 2015.

Short of an economic or political collapse, experts don't see much likelihood that China will abandon its slow, steady march to the stars. Too many dreams and ambitions are wrapped up in it.

"The average age of the Chinese space worker is 27," says Harvey. "These people are at the beginning of their professional careers. Just imagine them in 20 years, when they have experience and have learned from their mistakes. It's not a question of what will they do; it's a question of what will they not do."

—ELIZA STRICKLAND

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THE LONG MARCH TO SPACE

In just over 50 years, China has built a space program that can send humans into orbit and robots to the moon—and the country is expected to pass some more important milestones within a decade.

1958 China announces its space program.

1970 China launches its first Earth-orbiting satellite, Dongfanghong 1.

1984 China launches its first geostationary communications satellite.

2003 In the first Chinese human spaceflight mission, astronaut Yang Liwei orbits Earth 14 times in the Shenzhou 5 space capsule.

2007 The Chang'e-1 moon probe reaches lunar orbit.

2008 China becomes the third nation to carry out an extravehicular activity when astronaut Zhai Zhigang conducts a 20-minute space walk in Earth orbit.

2010 The Chang'e-2 lunar probe orbits the moon, capturing high-definition images of the lunar surface in preparation for a future lunar lander mission.

2011 China launches Tiangong-1, its first orbital space laboratory. The uncrewed space capsule Shenzhou 8 completes a rendezvous and docking maneuver.

2011 China's BeiDou Navigation Satellite System becomes operational for customers in China, with 10 satellites in use.

2012 The Shenzhou 9 space capsule brings three astronauts, including China's first female astronaut, to the Tiangong-1 space lab, where they spend 10 days.

2013 The Chang'e-3 lunar lander and rover are scheduled to reach the moon's surface in December.

2014 The first launch is expected at China's new spaceport, in Hainan.

2014-15 China's first space science satellites are expected to go into operation.

2015 China's next-generation heavy-lift rocket, the Long March 5, is scheduled to begin launches.

2017 The Chang'e-5 sample-return mission is scheduled to collect lunar soil and rocks and bring them back to Earth.

2020 China's first full space station is scheduled for completion.

2020 The BeiDou Navigation Satellite System is scheduled to begin providing global service using a fleet of 35 satellites.

DANGER, WILL ROBINSON

RESCUE-ROBOT SHOW-DOWN

Some may look like the Terminator, but these robots are designed to save us

"WHERE ARE THE ROBOTS?" That was what many people were asking when events at Japan's Fukushima nuclear power plant spiraled out of control in March 2011. With deadly levels of radiation collecting inside the damaged reactors, attempting to repair them became too dangerous for an emergency crew. Could Japan, a country known for its automated factories and advanced humanoids, use robots to take the place of human workers and stop the disaster in its tracks?

The answer, alas, was no: Robots are generally still too limited in what they can do. They may be great for carrying out repetitive tasks in clutter-free environments, but entering a rubble-strewn building, climbing ladders, using fire hoses–these operations are beyond today's best robots.

The U.S. Defense Advanced Research Projects Agency (DARPA) wants to change that. Fukushima was a wake-up call for the robotics community around the world, and DARPA responded by launching its biggest and most ambitious robot R&D program yet. Called the DARPA Robotics Challenge, or DRC, it aims to accelerate the development of robots that can help humans, not only with nuclear emergencies but also with fires, floods, earthquakes, chemical spills, and other kinds of natural and man-made disasters.

DARPA (some call it the mad science division of the Pentagon) organized the DRC as a kind of Olympic decathlon for robots, open to teams from anywhere on the globe. But instead of running, jumping, and throwing things, the robots will score points by performing various tasks in a simulated industrial disaster. Picture hulking machines driving vehicles, using power tools, and breaking through walls. And instead of a gold medal, the winning team will take home a US $2 million cash prize.

As of this writing, a preliminary contest, scheduled for December 2013, had not yet taken place, and the finals won't come until later this year. These robo-spectacles are certain to draw the attention of the tech world and the general public, raising the stakes for the DRC program. If it's a success, it will spawn a new generation of practical robots–and, perhaps inevitably, endless jokes about a robot uprising.

ILLUSTRATION BY Brian Stauffer

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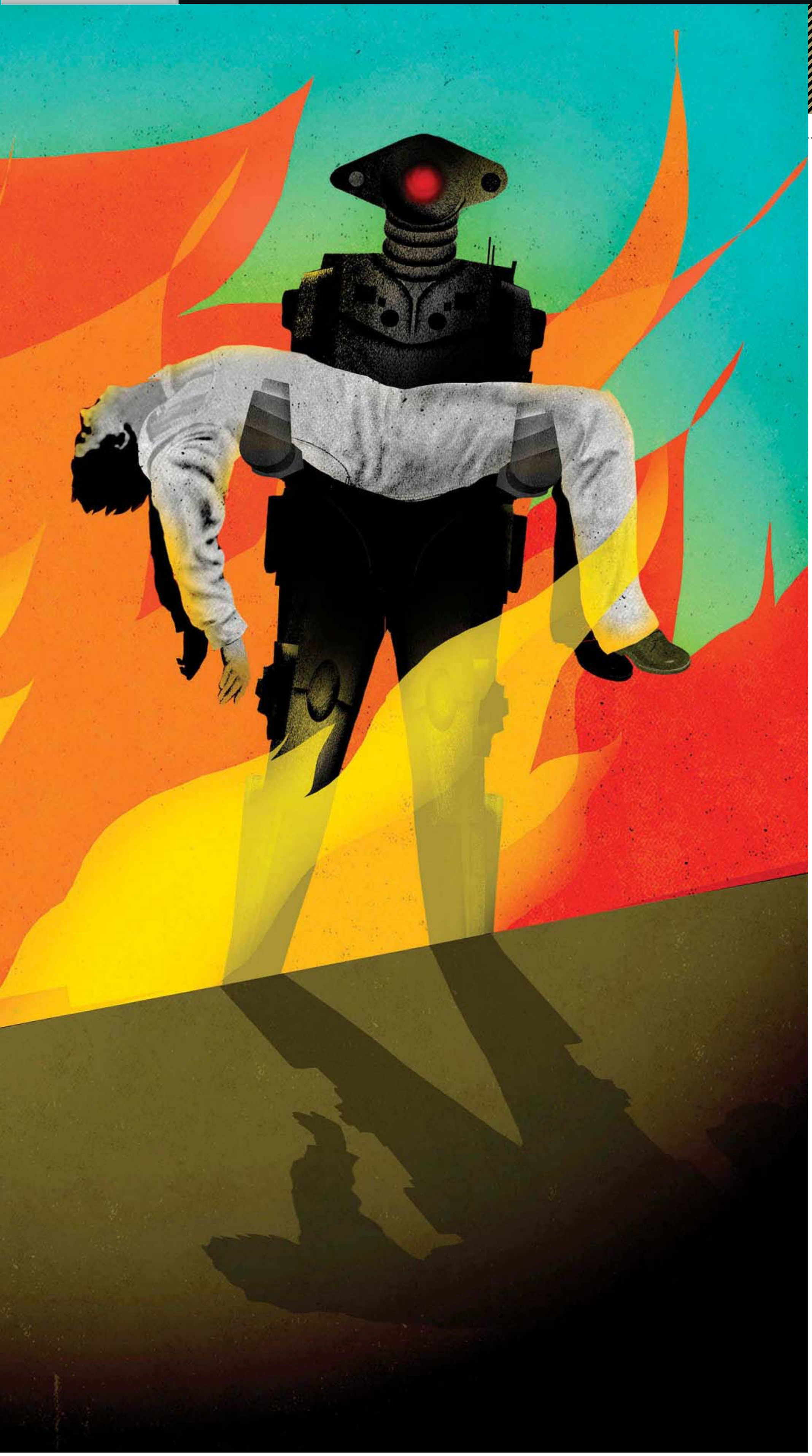

ROBOTS ARE NOT NEW to disaster response. In the 1980s, Carnegie Mellon University engineers built robots that entered and made repairs inside the damaged reactor at the Three Mile Island nuclear facility, in the United States, and at Chernobyl, in the former Soviet Union. One of the first reported uses of robots in a search-and-rescue operation was in 2001 at the World Trade Center, in New York City, after the 9/11 attacks.

Emergency workers all over the world have since been using small, remotely controlled vehicles equipped with cameras and sensors to locate victims and to map disaster sites. Most of these machines have tracks and look like tiny tanks. Some models have manipulators, but these are not strong or dexterous. In the aftermath of the Fukushima accident, some tracked robots were sent into the reactors, helping to assess the damage and perform cleanup tasks. The machines proved useful, but DARPA believes that disaster robots could do much more.

Organizers of the DRC hope to advance many aspects of robotics, including locomotion, manipulation, perception, and navigation. In the end, DARPA wants robots that can get around as easily as human rescue workers do. Mechanical first responders should also be able to use vehicles and tools designed for people. The DRC

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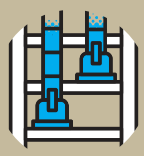
THE CHALLENGE IS *ON*

The robots competing in the DARPA Robotics Challenge face eight complex tasks based on a disaster-response scenario. The tasks are designed to test perception, dexterity, endurance, and other capabilities. The team whose robot scores the most points wins US $2 million.

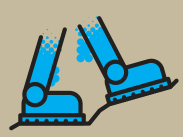
1. DRIVE A VEHICLE

Robots must drive a utility vehicle across a 76-meter obstacle-laden track.



5. CLIMB A LADDER

Robots must climb a narrow industrial-type ladder with a 60-degree incline.

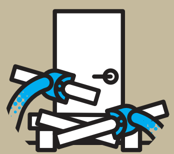


2. TRAVEL DISMOUNTED

Next, robots need to traverse a rough-terrain course covered with tripping hazards.

6. BREAK THROUGH A WALL

Using power tools—and their own hands—robots have to break panels of drywall.

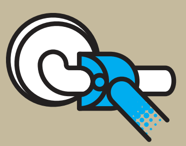


3. REMOVE DEBRIS

This task requires robots to clear lumber and pipes that are blocking an entryway.

7. CLOSE VALVES

Robots need to locate and close different kinds of valves on a wall and a table.



4. OPEN DOORS

Robots face a push door, a pull door, and a door with a self-closing hinge.

8. CONNECT A FIRE HOSE

Finally, robots must pick up a fire hose, unspool it, and connect it to a fire hydrant.

requires that the machines be able to exercise a great deal of autonomy, performing tasks with minimum supervision.

That's a ridiculously ambitious goal. To put things into perspective, consider today's most advanced robots. Some, like Honda's Asimo and South Korea's Hubo, can walk and even run. Others, including NASA's Robonaut and Germany's Rollin' Justin, can grasp and use tools. And PR2, developed by the Silicon Valley lab Willow Garage, can map its environment, drive around, and handle objects. A host of tracked vehicles, like iRobot's PackBot, used to disarm bombs, can negotiate rough terrain and perform manipulations. But a robot that can do all that while operating in a deteriorated environment with limited access to communication and power, as DARPA is aiming for, is unheard of. That goal could easily take a decade or two, but the sponsors of the DRC want to show significant progress in just two years.

As Dennis Hong, a roboticist at Virginia Tech, put it, the pace has been "insane." His team is building a humanoid called THOR (Tactical Hazardous Operations Robot), powered by linear actuators that Hong and his colleagues are engineering from scratch.

Although THOR and other DRC contenders have humanoid forms, teams are free to design any kind of machine they want. So it's possible that at the finals we may see robots with distinctly nonhuman shapes or features that enhance their capabilities. The Carnegie Mellon team, for example, is building CHIMP (CMU Highly Intelligent Mobile Platform), which looks like a cross between an ape and a tank. Its limbs have tracks at their extremities, to assist with locomotion over uneven terrain.

DARPA tried to make the program as open as possible, and more than 100 teams registered. In the end, only a dozen or so are expected to make it to the finals. The agency provided some of the teams with financial support. Others are self-funded.

To make the DRC accessible to groups that couldn't afford to build their own robots, DARPA organized a virtual competition, which took place in June. Teams not building hardware had to use a simulator, developed by the Open Source Robotics Foundation, to program a virtual humanoid to perform some of the tasks that will be judged in the real contest.

But here's the best part: The top performers in the virtual competition were each allowed to borrow a $2 million robot from DARPA for the upcoming hardware

FUN FACT: The Atlas robot built for the DARPA Robotics Challenge is so strong that it can kick cinder blocks and reduce them to dust.

ILLUSTRATIONS BY James Provost

ROBOT RESCUERS: CHIMP [top] and Atlas are two robots competing in DARPA's simulated disaster response.

FROM TOP: NATIONAL ROBOTICS ENGINEERING CENTER/CARNEGIE MELLON UNIVERSITY; DARPA

face-off. The robot, called Atlas, was built by Boston Dynamics, most famous for its BigDog quadruped. Powered by hydraulic actuators, Atlas is nearly 2 meters tall and weighs 150 kilograms—as much as a large refrigerator. In a video demo, a 9-kg wrecking ball hanging by a strap slams into Atlas as it stands on one foot; the robot quickly adjusts its balance.

For teams that receive an Atlas loaner, a big challenge is transferring what they accomplished in simulation to the real robot, where every move must be carefully executed. Make an error in the control algorithm and your Atlas might come crashing down face first. One team reported that a buggy line of code nearly sent one of Atlas's feet into its own chest. Another said that while they were teaching Atlas to walk over concrete blocks, the robot ended up kicking the blocks with enough force to destroy them.

In simulation, you can always try new things and start it all over when it doesn't work, says Michael Gennert, one of the leaders of the Worcester Polytechnic Institute team. With a $2 million robot, not so much. "You can't just reboot it after a crash," he says.

DARPA SPECIFICALLY mentions the Fukushima accident as an example of a disaster that would have benefited from more capable robots. Indeed, the scenario DARPA is planning for the final competition closely resembles the dramatic events that unfolded in the first 24 hours of the Fukushima catastrophe, when workers attempted but ultimately failed to fix one of the crippled reactors.

DRC program manager Gill Pratt rejects the notion that the tasks DARPA has concocted for the robots might be too difficult given the current state of the art. In the agency's parlance, the tasks are "DARPA hard," he says, but not impossible. "It's a goal that has a lot of risk but a lot of reward as well, and that's really the theme of what DARPA tries to do."

Most teams that *IEEE Spectrum* spoke with don't expect to put on an exceptional performance during the preliminary contest. But they're hopeful that later this year their robots will do much better. So you might see a repeat of what happened with the DARPA challenges for self-driving vehicles. The first was a big failure: Most vehicles barely made it out of the starting gate. But the following races were a different story. The robotic vehicles were able to drive themselves admirably, first through the desert and later around a mock city. Some of their designers went on to work for Google, developing its now-famous self-driving cars.

The same could happen with the DRC. And even if the challenge fails to foster the creation of practical disaster robots in the near future, it will certainly show their possibilities and propel many technologies forward.

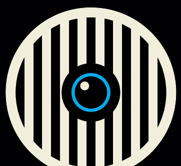
"The actual competition robots are prototypes and not yet ready for deployment," says Seth Teller of the MIT team. "But the DRC is a first and important step toward a future in which, even as disasters like Fukushima unfold, people will be able to send machines to do their bidding." —ERICO GUIZZO

POST YOUR COMMENTS at http://spectrum.ieee.org/robot0114

HONORABLE MENTION

GOOOOOOOOAALLL!

High-speed cameras and smart watches will verify goals at the 2014 World Cup



AT THIS SUMMER'S FIFA World Cup soccer tournament in Brazil, an electronic referee will join the whistle-blowing kind. GoalControl, of Würselen, Germany, will position 14 high-speed cameras on the field as part of its GoalControl 4D system. When the system detects that a goal has been scored, it will send a vibration and a text alert to officials' watches. Miscalled goals should be a thing of the past. —TEKLA S. PERRY

ICON BY Greg Mably

ILLUSTRATION BY Eddie Guy

LOOK, MA, NO PILOT

SOLARA TAKES OFF

Titan Aerospace's high-flying drones could deliver satellite services without leaving the atmosphere

IF YOU TAKE THE MAIN ROAD east out of Moriarty, N.M., turn south at a sign advertising glider rides, and then swing east again past the sailplanes ornamenting a two-runway airport, you will see hangar No. 76, the headquarters of Titan Aerospace. In this cavernous office-cum-workshop, engineers are developing the Solara—a line of solar-powered robotic airplanes capable of staying aloft for years at a time.

The first of these planes, the Solara 50, will be equipped with about 3000 photovoltaic cells covering a 50-meter wingspan—as long as an Olympic swimming pool. The aircraft is meant to carry a small payload to altitudes around 20 kilometers into the stratosphere, where the air is idyllically calm.

The Solaras and their ilk are sometimes called atmospheric satellites, because they could do many jobs that satellites do, including delivering broadband service and taking pictures from on high. But unlike stationary orbiters, these planes could be retrieved, upgraded, and reused. And because they could be bought and operated for a fraction of a satellite's cost, they could take on other missions, such as patrolling national borders, monitoring the ozone layer, and expanding cellular coverage. The Solara 50 could be the first commercial product to provide these services.

"Trying to find a customer to sell this airplane to isn't going to be a problem for us," says Vern Raburn, Titan's CEO. He expects engineers will test-fly the first full-scale models later this year. Provided there are no major hang-ups, he says, the plane should go on sale in 2015.

Titan isn't the first company with such ambitions. In 1974, engineers at AstroFlight, a model airplane manufacturer in Irvine, Calif., guided the first robotic solar plane over a dry lake bed. In the 1980s, AeroVironment, now in Monrovia, Calif., claimed the first piloted solar flight and the first solar-powered crossing of the English Channel. With funding from NASA, the company pushed solar drones to greater and greater heights, ultimately achieving a 40-minute tour above 29 kilometers in 2001. And in 2010, the British defense firm QinetiQ proved

40 YEARS OF SOLAR AVIATION

Sunrise I
FEAT: First solar-powered flight
MAKER: AstroFlight
FLIGHT DATE: 1974
LOCATION: Fort Irwin, Calif.
ALTITUDE: 100 meters
DURATION: 20 minutes
FATE: Damaged in a sandstorm

Gossamer Penguin
FEAT: First piloted solar flight
MAKER: AeroVironment
LOCATION: Shafter, Calif.
DATE: 1980
ALTITUDE: No more than a few meters
DURATION: Several minutes
FATE: Retired

Zephyr
FEAT: Longest pilotless flight
MAKER: QinetiQ
LOCATION: U.S. Army Yuma Proving Ground, Ariz.
DATE: 2010
ALTITUDE: 21 500 meters
DURATION: 14 days, 22 minutes
FATE: Sold to Astrium in 2013

FROM TOP: ROLAND BOUCHER; BOB RHINE/NASA; QINETIQ

the feasibility of long-duration flights by keeping its hand-launched Zephyr up in the air for two weeks.

Yet no company could commercialize a reliable system. Success was stymied by inefficient photovoltaics, limited battery capacity, and the fragility of the ultralight airframes, which can be easily battered while climbing through the atmosphere's turbulent lower layers. "If you look at the history of these projects, you'll notice almost all were destroyed because they flew through a little bit of weather," says Kevin Jones, an aerospace engineer at the Naval Postgraduate School, in Monterey, Calif.

Raburn says that key technologies have now matured enough to bring such a plane to market. Solar-cell efficiency, for example, has climbed from 10 percent in the 1970s to around 40 percent today. Battery technology has made similar strides in energy density, packing in ever more joules per gram. Meanwhile, advanced carbon-fiber composites are enabling stronger, more durable frames. "It's the classic confluence of technologies," he says.

Jones agrees but says that although months aloft are doable, longer missions may still be a few years off. Even the best rechargeable batteries can be replenished only so many times before they stop holding enough charge to last through the night. "With lithium, getting above 200 cycles is challenging," he says. That would limit flights to about six months. Some researchers believe that using fuel cells could extend flight time to several years.

Soon you'll be able to stand in your backyard at dusk and spot them—twinkles of light floating at the edge of the atmosphere. At long last, the eternal aircraft may be within reach. —ARIEL BLEICHER

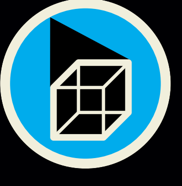
FUN FACT: The inaugural flight of the first piloted solar plane, the Gossamer Penguin, was piloted by the engineer Paul B. MacCready Jr.'s 13-year-old son, Marshall.

POST YOUR COMMENTS at http://spectrum.ieee.org/solara0114

·HONORABLE MENTION·

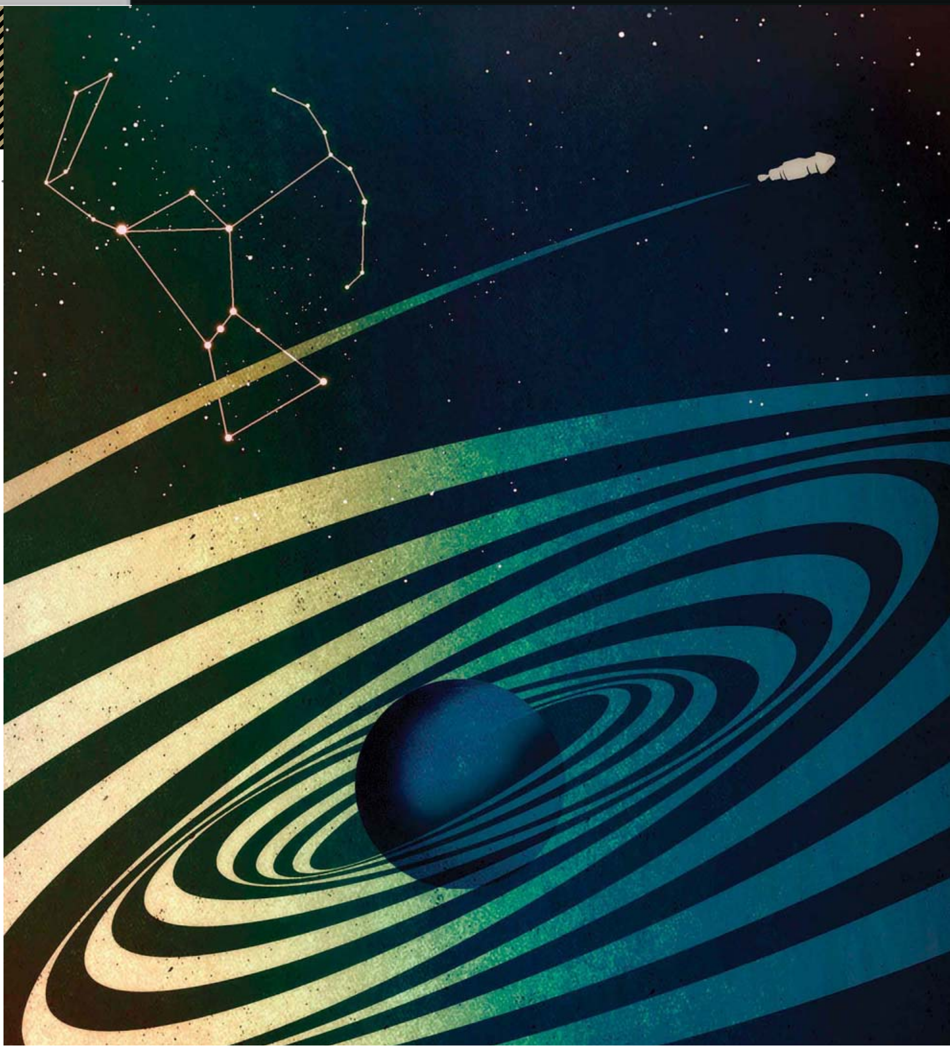
3-D PRINTING PRICES TO PLUMMET?

High-end printers could proliferate when key patents expire



WHILE HOBBYIST 3-D printers are abundant and cheap, costing as little as US $300, companies still shell out tens of thousands of dollars for industrial-grade machines. These high-resolution fabricators make wedding rings, robotic hands, and countless more creations and components using a technique known as selective laser sintering, in which lasers fuse portions of a growing powder mass to erect a 3-D form. But this year, key patents on the technology, owned by 3D Systems, will expire. So expect competition to rise and prices to plummet. That could very well usher in the manufacturing revolution we've all been waiting for. —A.B.

ICON BY Greg Mably



A ROOM WITH A VIEW—FROM SPACE

TO LOW EARTH ORBIT AND BEYOND

The Orion crew capsule carries NASA's hopes for revival

NASA HAS FOUND ITSELF curiously earthbound of late. Since it retired the space shuttles in 2011, the U.S. space agency has had to send astronauts to the International Space Station aboard Russian rockets.

But NASA has its sights set on targets well beyond low Earth orbit. And this September, the agency will make its first step toward getting astronauts there, with the first launch of an Apollo-inspired crew module called Orion.

This test drive won't carry humans—or even seats, for that matter—but it will go a long way toward proving that the agency's human exploration program is alive and well. The hope is that Orion and a new heavy-lift rocket, also in development, will be ready to send astronauts back into lunar orbit by 2021. That would be just shy of the 50th anniversary of Apollo 17, the last of NASA's crewed moon missions.

In many ways, Orion follows in Apollo's footsteps. It launches on top of a rocket, just as the Apollo crew capsules did (and as Russian and Chinese capsules do today). It also splashes down in the ocean when it returns. Where it differs is in scale: Apollo supported three astronauts for less than two weeks, but Orion will be about 30 percent bigger, with enough space to support four astronauts for 21 days, or fewer astronauts for longer periods.

According to a controversial plan announced in April, the astronauts would get into lunar orbit and then investigate a small space rock that a previous robotic mission would have placed near the moon after plucking it from its original orbit. After that, the agency says, Orion could be paired with other modules yet unbuilt. These could provide enough extra propulsion and living space to take Orion crews to Mars. "That's the beauty of the design—it's very flexible," says Orion program manager Mark Geyer, who is based at NASA's Johnson Space Center, in Houston.

Such trips will take their toll, however. Spacecraft returning from Earth orbit hit the atmosphere at about 28 000 kilometers per hour, but those heading back from the moon come screaming

ILLUSTRATION BY Brian Stauffer

FUN FACT: Orion won't carry either people or seats on its maiden flight.

NASA

ORION'S ROAD AHEAD

2014: EXPLORATION FLIGHT TEST-1
An uncrewed Orion spacecraft makes its first jaunt into space, orbiting twice around Earth.

2017: EXPLORATION MISSION 1
Orion is paired with the Space Launch System (SLS), a new heavy-lift rocket. The spacecraft, again uncrewed, may go around the moon before returning to Earth.

2018: ASCENT ABORT 2
A rocket-powered cap designed to separate the spacecraft from the launcher is tested at high altitude.

2018: ASTEROID REDIRECT ROBOTIC MISSION
A robotic spacecraft launches into deep space to rendezvous with and capture a space rock and bring it close to the moon.

2021: EXPLORATION MISSION 2
Orion takes its first crew into space, potentially to the moon, to investigate the retrieved space rock.

in at some 40 000 km/h, raising the temperature of a craft's exterior to about 2700 °C. One major goal of Orion's maiden flight is to test the capsule's 5-centimeter-thick epoxy heat shield.

The capsule will be launched from Florida atop a Delta IV Heavy rocket and loop around Earth twice, reaching an altitude of about 5800 km–some 15 times as high as the International Space Station. Then it will dive back into the atmosphere at more than 32 000 km/h, 84 percent of the speed of a return from the moon. As it descends, the craft will reach temperatures of more than 2200 °C, some 500 degrees cooler than in a real lunar return.

The flight will also test the capsule's parachutes, which will slow the craft down before it splashes into the water off the coast of California. The parachutes have already been dropped from aircraft to test them in the atmosphere, but because the chutes interact as they open, it's important to subject them to the "exact environments and speeds that we're going to see with people," Geyer says. Engineers will also be watching to make sure that the cover that sits over the chutes ejects as designed after a pyrotechnic device is fired.

Two more test flights are planned in order to prove Orion ready to carry people. One will come in 2017, when Orion will be paired with the new Space Launch System (SLS), which will most likely send it on a jaunt around the moon. Another flight will test an escape mechanism that Apollo had but the space shuttle did not–a rocket-powered cap that would blast Orion away from its launcher in an emergency.

The SLS will boast at least 10 percent more thrust than the Apollo program's Saturn V, the most powerful rocket flown to date.

The road ahead is uphill. A recent report from NASA's inspector general says that the agency is tracking 248 technical issues with the Orion program. And it warns that the program's flat funding projections leave a thin cushion in the budget to deal with any snags that may arise. Indeed, NASA's departing deputy administrator, Lori Garver, said in September that the 2017 uncrewed flight with the SLS and the first crewed flight in 2021 already look like they might be delayed by a year or two.

Still, the journey of a thousand miles begins with a single step, and this year's test could pave the way for more ambitious missions. "If I were back in the astronaut corps, I would be looking forward with great desire to be able to go beyond Earth orbit," says Jeffrey Hoffman, a professor of astronautics at MIT and a former space shuttle astronaut. "Let's hope that the astronauts of a decade from now will get a chance to do that."

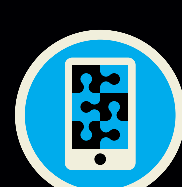
—MAGGIE MCKEE

POST YOUR COMMENTS at http://spectrum.ieee.org/orion0114

·HONORABLE MENTION·

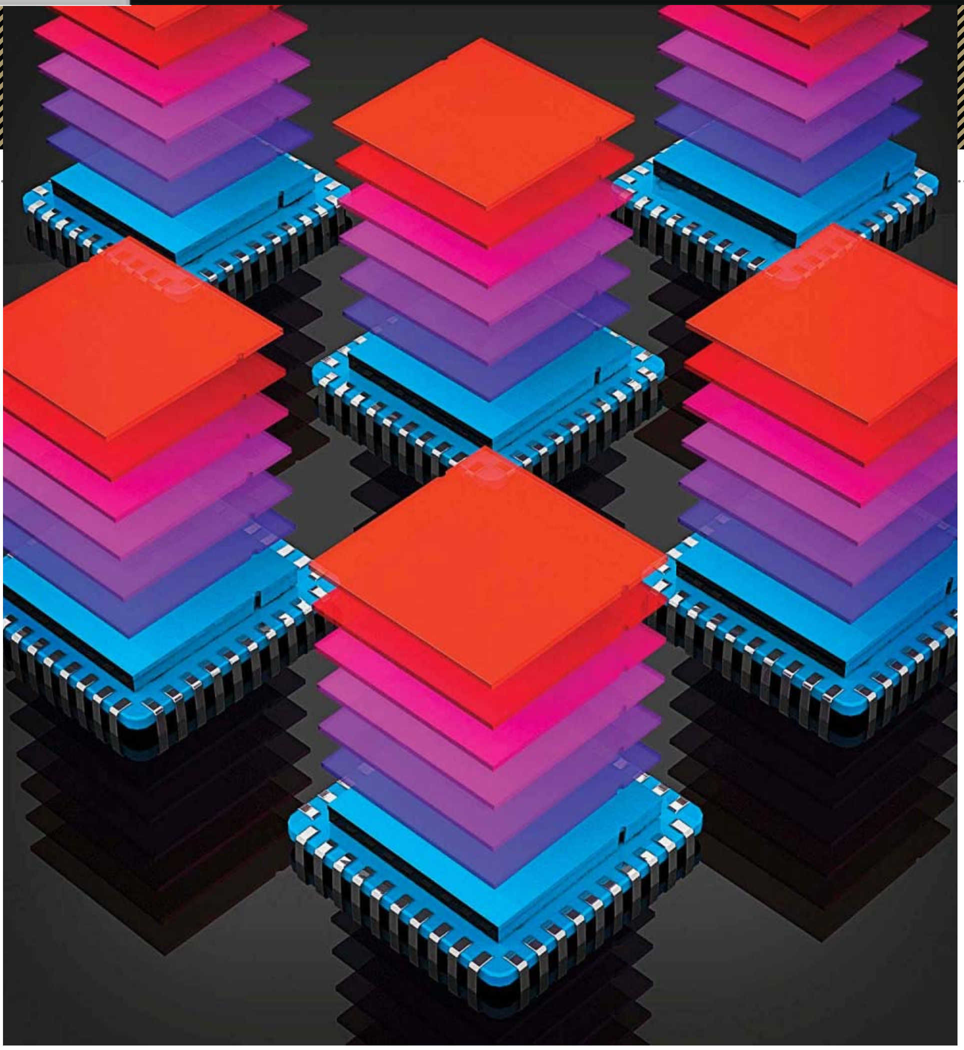
A SMARTPHONE MEANT TO LAST

You may never have to throw away a handset again



YOU'LL SOON be able to buy a phone that outlasts its parts if Project Ara pans out. Ara, led by Google-owned Motorola Mobility, aims to make smartphones that users can upgrade or customize at will. Broken screen? Just snap on a new one. Sluggish memory? Pop in the latest chip. Ara's designers have promised a developer's kit by early this year, so it's possible that handsets will go on sale before December. —ARIEL BLEICHER

ICON BY Greg Mably



COMING SOON, IN 3-D

MEMORY IN THE THIRD DIMENSION

Chip stacking and transistor redesigns will make memory smaller and faster

A 3-D REVOLUTION IS SLOWLY making its way across the chip industry. Intel set it off in 2011 when it debuted logic chips bearing transistors that pop out of the plane of the chip. This year, memory makers are joining the game with two innovations of their own.

If you upgrade your smartphone in 2014, chances are you won't see either of these technologies inside it. They will appear first in high-performance (and high-margin) processors and solid-state drives. But analysts say it's only a matter of time before these 3-D memories migrate to consumer gadgets. And that could mean big gains in speed and storage space.

One of the 3-D memory movements centers on NAND flash, a memory that's nonvolatile—that is, it holds on to information even when it's powered down. This flash memory is already used to store data in smartphones, tablets, and many laptops and is supplanting hard drives inside data centers.

Flash stores data in transistors, by injecting or draining electrons from a conductive patch called a floating gate. The value of a gate can be read because the electrons inside it alter the conductivity of an adjacent current-carrying channel.

But flash, which celebrated its 25th anniversary in 2012, is now showing its age. As chip features shrink, cells sit closer and closer to one another, increasing interference and the chance of corrupted data. What's more, fewer electrons—mere dozens in today's most advanced versions—can be fit inside any cell. As a result, cells are more liable to leak charge and be affected by tiny changes.

Memory designers reckon the solution lies in the third dimension. And the first company with a fix is top memory maker Samsung, which announced in August that it had already started production on a 128-gigabyte "vertical" NAND chip. SK Hynix, another South Korea-based firm, and Micron, based in Boise, Idaho, should ship 3-D NAND chips this year.

The companies are expected to turn each line of memory cells on its side, stringing them vertically in a forest of pillars. This

ILLUSTRATION BY Eddie Guy

FUN FACT: When it comes to memory manufacturing, consolidation is king. Today only three major DRAM manufacturers remain: Micron, Samsung, and SK Hynix

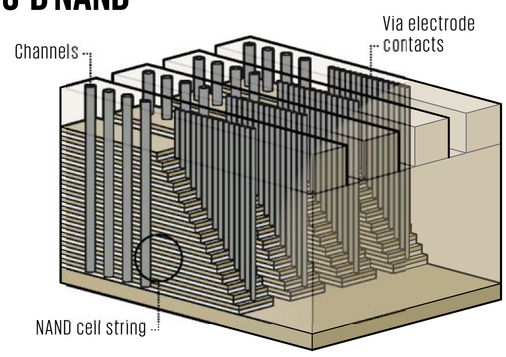
will allow the memory manufacturers to take what's essentially a right turn around Moore's Law: They'll pack more bits together not by shrinking features but by layering cells.

The change in architecture is expected to drive down the cost per bit and relax lithographic printing requirements. Indeed, Samsung's new 3-D cells are likely made with a 30- to 40-nanometer process, a few generations behind the current, 20-nm class, says Dee Robinson, a senior analyst at IHS in El Segundo, Calif. With bigger cells and more electrons, Robinson says, "it's actually a better performing chip." She adds that it's still unclear how quickly the cost of the new technology will decline to match that of traditional 2-D flash. But IHS estimates that 3-D flash will make up more than half of the NAND market by 2017.

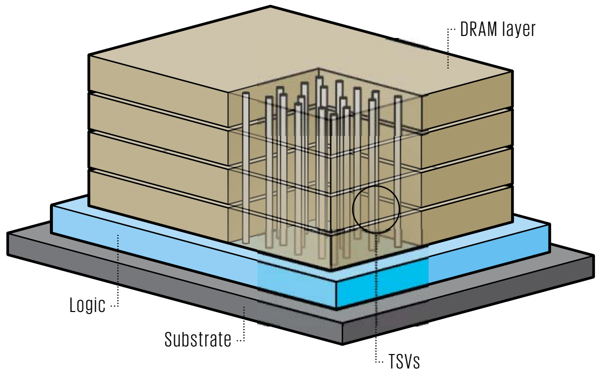
The move carries some risk. "It involves technologies that have never been put into production before," says analyst Jim Handy of Objective Analysis in Los Gatos, Calif. While some flash manufacturers are moving to 3-D, others, such as Intel, SanDisk, and Toshiba, are expected to stick with planar NAND for the moment, by taking advantage of new insulating materials. But they will inevitably be forced to switch to 3-D, Handy says.

A second 3-D technology–the Hybrid Memory Cube,

3-D NAND



HYBRID MEMORY CUBE



TWO TAKES ON 3-D MEMORY: To boost density and alleviate scaling issues, 3-D NAND [top] stands the traditional planar channel, and the line of memory cells arranged along it, straight up. A second 3-D technology, the Hybrid Memory Cube [bottom], will stack DRAM and add a layer of logic to boost speed.

or HMC–will also be ramping up in 2014. This effort focuses not on storage but on the computer's memory workhorse: dynamic RAM.

The HMC won't be any denser, smaller, or cheaper than an ordinary DRAM chip–it'll be faster. It's designed to surmount the "memory wall," a communications bottleneck that has developed between multicore CPUs and memory, says Mike Black, a technology strategist at Micron. "The latest generations of high-performance CPUs are not capable of getting access to enough memory bandwidth," Black says.

Micron developed the HMC in collaboration with SK Hynix and Samsung as well as more than 100 other semiconductor firms, research institutions, and potential customers. Their aim was to change the way systems handle DRAM signals. Instead of forcing DRAM chips to drive communications straight to a processor, the HMC off-loads most of that responsibility to a high-speed logic chip. DRAM dies are stacked atop this logic layer and are connected using thousands of copper wires called through-silicon vias (TSVs).

These vias allow the DRAM chip broad access to its bus; the logic layer cuts the number of connections that information must traverse on its way to the CPU. "This is the first commercial memory product offering [TSVs] as a standard part of the construction," Black says.

Micron announced in September that it had begun shipping the first samples of its 2-GB memory cube. They're expected to be produced at volume later this year, along with a 4-GB version. A single cube can offer 160 gigabytes per second of bandwidth, Micron says, compared with about 12 GB/s for current DRAM and 20 for the next generation, DDR4.

The HMC is quite fast, says Handy of Objective Analysis, but its success will hinge on finding a sufficiently large market to drive down costs. A large player such as Intel could sway the technology's fate. But "so far," he says, "Intel's been playing it close to the vest."

—RACHEL COURTLAND

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ILLUSTRATION BY James Provost

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their use of different time-frequency resources.

For networks using only one frequency channel, eICIC offers a different solution. It permits the macrocell to mute data traffic and reduce the power of control signals at particular 1-millisecond time intervals, called subframes. A small cell can then schedule both control and data transmissions during these times, allowing it to expand its coverage range. This technique lets more users link to the small cell, which provides more data capacity.

The last major item on LTE-Advanced's broad menu helps further improve signals and increase data rates at a cell's edge, where it can be tough to get a good connection. The technique is called **coordinated multipoint**, or CoMP. Essentially, it enables a mobile device to exchange data between multiple base stations at the same time. For example, two neighboring base stations could send the same data to the device simultaneously, increasing its chance of getting a decent signal. Likewise, the device could upload data to both base stations at once, and the stations, acting as a virtual antenna array, would jointly process the signals to eliminate errors. Or the device might instead choose to upload to a nearby small cell, saving transmission power while still receiving a strong download signal from a larger tower.

IT WILL TAKE YEARS FOR operators to make use of everything that LTE-Advanced has to offer. Many carriers have yet to deploy some of the more sophisticated features of LTE, such as voice services and "self-organizing" software, which would let base stations adapt to new network conditions on their own or heal themselves after a disruption.

Meanwhile, the evolution of LTE won't end with LTE-Advanced. The 3rd Generation Partnership Project, the international body behind the standard, plans to release the next iteration later this year. Some companies are calling it LTE-B, although the 3GPP disapproves, asserting that all future breeds of LTE will still be officially titled LTE-Advanced. Whatever its name, the new variant will offer operators even more radical options, including protocols for three-dimensional antennas, more energy-efficient transmissions, and direct communication between mobile devices and other smart sensors and machines. Together, such breakthroughs could give networks some 30 times as much capacity as LTE-Advanced. Now that's something worth waiting for.

—ARIEL BLEICHER

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science. The NSF's reports echo many of the NIH report's priorities, calling for the development of technologies to map brain structure and activity; they also emphasize the need for sophisticated new methods to store and analyze the massive amounts of data that will result from large-scale mapping efforts.

DARPA's role is more mysterious. The defense agency will likely look at promising near-term applications for soldiers, such as improvements on existing brain-imaging technologies that can aid soldiers with brain injuries, but it may also take a chance on seemingly improbable ventures. Its existing neuroscience programs offer some hints that DARPA is interested in neurally enhanced soldiers: One project seeks interventions that can reduce the negative impact of stress. Other DARPA projects focus on cyborg-style fixes for injured soldiers, such as neurally linked prosthetic limbs and neural prosthetics that could replace lost cognitive or memory function.

"The feeling is that whatever path we go down, it will usher in a new era," says Herbert Levine, a Rice University professor of bioengineering who coauthored one of the NSF's BRAIN reports. A concern of Levine and others, though, is whether Congress will continue to fund the project, which doesn't yet have a federal budget beyond 2014. Continued funding is expected but hardly assured, and will be decided in the next year.

As BRAIN proponents push for funding, they'll have to walk a fine line of self-promotion. The project's potential applications for self-understanding, the treatment of disease, and prosthetics are clear, but it's unrealistic to expect breakthroughs, much less cures or answers to existential questions, in the next few years. At the same time, Congress and the public may have little patience for theoretical insights and the slow pace of basic research. Scientists may be tempted to overpromise, setting the stage for eventual disappointment and backlash. As difficult a sell as it may be, the BRAIN Initiative should be embraced for what it is: a grand, ambitious voyage into the unknown.

—BRANDON KEIM

FUN FACTS:

ROUNDWORM: 302 neurons
FRUIT FLY: 100 000 neurons
MOUSE: 75 million neurons
CAT: 1 billion neurons
CHIMPANZEE: 6.7 billion neurons
HUMAN: 86 billion neurons

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Technical University of Denmark DTU

PROFESSOR – Algebra with Applications

DTU Compute invites applications for a position as Professor (with special responsibilities) in Algebra with Applications. DTU Compute is a department with the overall mission of contributing to research, development and education within applied mathematics and computer science The professor will be attached to the section for Mathematics one of the 11 sections comprising the Department employing approximately 325 persons including presently a faculty of 90.

Application deadline: **1 March 2014**

DTU is a technical university providing internationally leading research, education, innovation and public service. Our staff of 5.000 advance science and technology to create innovative solutions that meet the demands of society; and our 9.000 students are educated to address the technological challenges of the future. DTU is an independent academic university collaborating globally with business, industry, government, and public agencies.

Further details: career.dtu.dk

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See our PhD-programmes at dtu.dk/phd

ShanghaiTech University Faculty Search

The newly launched *ShanghaiTech University* invites *highly qualified* candidates to fill multiple tenure-track/tenured faculty positions as its core team in the School of Information Science and Technology (SIST). Candidates should have exceptional academic records or demonstrate strong potential in cutting-edge research areas of information science and technology. They must be fluent in English. Overseas academic connection or background is highly desired.

ShanghaiTech is built as a world-class research university for training future generations of scientists, entrepreneurs, and technological leaders. Located in Zhangjiang High-Tech Park in the cosmopolitan Shanghai, ShanghaiTech is ready to trail-blaze a new education system in China. Besides establishing and maintaining a world-class research profile, faculty candidates are also expected to contribute substantially to graduate and undergraduate education within the school.

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

Compensation and Benefits: Salary and startup funds are highly competitive, commensurate with experience and academic accomplishment. We also offer a comprehensive benefit package to employees and eligible dependents, including housing benefits. All regular ShanghaiTech faculty members will be within its new tenure-track system commensurate with international practice for performance evaluation and promotion.

Qualifications:

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

Applications:

Submit (in English) *a cover letter, a 2-page research plan, a CV plus copies of 3 most significant publications, and names of three referees* to: **sist@shanghaitech.edu.cn** by March 31st, 2014 (until positions are filled). *For more information, visit http://www.shanghaitech.edu.cn.*

BAYLOR UNIVERSITY

The Electrical and Computer Engineering Department of Baylor University

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

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

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

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

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

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

FACULTY POSITION

Electrical Engineering: Neuroscience and Data Science

NYU SHANGHAI

NYU Shanghai is currently inviting applications for one position at all levels (assistant, associate, and full professor) from outstanding candidates having demonstrated abilities in both research and teaching. We are interested in candidates with a Ph.D. in Electrical Engineering (or related field) whose research interests are in either of the following two research areas: (1) neuroscience, including brain-machine interfaces and computational neuroscience; or (2) data science, including machine learning and deep learning. When discussing their teaching experience, candidates should identify courses they could teach both within and outside their specialty.

Candidates must have completed a Ph.D. or equivalent by the time of appointment. The search will remain open until the position is filled, but review of applications will begin November 15, 2013. The appointment could begin as soon as September 1, 2014, pending administrative and budgetary approval, or could be delayed until September 1, 2015.

NYU Shanghai is the first Sino-US higher education joint venture to grant a degree that is accredited in the US as well as in China. A research university with liberal arts and sciences at its core, it resides in one of the world's great cities, which is also a vibrant intellectual community (http://shanghai.nyu.edu/). NYU Shanghai will recruit scholars who are committed to our global vision of transformative teaching and innovative research.

New York University has established itself as a Global Network University, with three degree-granting campuses - New York, Shanghai, and Abu Dhabi - complemented by 12 additional academic centers across five continents. Faculty and students circulate within the network in pursuit of common research interests and cross-cultural, interdisciplinary endeavors, both local and global.

The terms of employment in NYU Shanghai are comparable to U.S. institutions. Faculty may also spend time at NYU New York and other sites of the global network, engaging in both research and teaching opportunities.

Applicants should submit curriculum vitae, a statement of research and teaching interests, electronic copies of up to five recent relevant publications, and the names and addresses of three or more individuals willing to provide letters of reference by ***January 31, 2014***. Please visit our website at **http://shanghai.nyu.edu/about/open-positions-faculty** for instructions and other information on how to apply. If you have any questions, please e-mail **shanghai.faculty.recruitment@nyu.edu**.

上海纽约大学 NYU SHANGHAI

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Department of Electrical Engineering

UNIVERSITY OF MINNESOTA DULUTH

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Minnesota Power Jack Rowe Endowed Chair in Electrical Engineering

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

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

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

NAZARBAYEV UNIVERSITY

Faculty positions in Robotics and in Computer Science

SCHOOL OF SCIENCE AND TECHNOLOGY

NAZARBAYEV UNIVERSITY

ASTANA, KAZAKHSTAN

Nazarbayev University is seeking highly qualified full-time faculty at all ranks to join its rapidly growing programs in Robotics and Computer Science in the School of Science & Technology. Successful candidates must have an earned Ph.D. degree from an accredited university, excellent English-language communication skills, a demonstrated ability for research, 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.

All suitable candidates will be reviewed. Applications are particularly encouraged from candidates with research interests that align with our focus areas of Embedded Systems, Industrial Automation and Manufacturing (Department of Robotics) and Computer Systems, Intelligent Systems, Mobile Computing, Information Security, and Software Engineering (Department of Computer Science).

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

To Apply: applicants should send a detailed CV, including qualifications, experience, and list of publications to sst@nu.edu.kz. Review of applications will begin immediately.

THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Faculty position in Electronic and Computer Engineering

The Department of Electronic and Computer Engineering (ECE) at the Hong Kong University of Science and Technology invites applications for several tenure-track faculty positions.

(1) One position at the rank of Assistant/Associate/Full Professor in the area of Robotics and Autonomous Systems (areas in Unmanned Aerial Vehicles, Reinforcement Learning, Bio/Healthcare Robotics, Nonlinear Dynamic Control, Manufacturing Automation will be a plus).

(2) One position at the rank of Assistant/Associate/Full Professor in the area of Display Technologies.

Applicants should have a PhD with demonstrated strength in research and a commitment to teaching. Successful candidates are expected to lead an active research program, and to teach both graduate and undergraduate courses. In both cases the area specified should be considered broadly. We may also consider candidates at the rank of Assistant Professor who have an exceptionally outstanding record of research accomplishments in the following themes:

- Machine Learning Theory (with preference on bio-system, bio information)
- Big Data Systems
- Energy and Green ICT

The Hong Kong University of Science and Technology is a world renowned, international research university in Asia's most vibrant city, Hong Kong. Its Engineering School has been consistently ranked among the world's top 25 since 2004. The high quality of our faculty, students and facilities provide for outstanding opportunities for faculty to pursue highly visible research programs. All formal instruction is given in English and all faculty members are expected to conduct research and teach both undergraduate and graduate courses. The Department of ECE has excellent computing resources, and state-of-the-art teaching and research laboratories. Currently the Department has about 40 faculty members, 800 undergraduate students and 350 postgraduate students. The University is committed to increasing the diversity of its faculty and has a range of family-friendly policies in place.

Starting salary will depend on qualifications and experience. Fringe benefits including medical and dental benefits, annual leave and housing will be provided where applicable. Initial appointment will normally be on a three-year contract. A gratuity will be payable upon successful completion of contract. Re-appointment will be subject to mutual agreement.

Applications including full curriculum vitae, list of publications, names of five referees addressed to Professor Vincent Lau, Chair of the Search Committee, and should be sent by email to eesearch@ust.hk. Applications will be considered until the position is filled.

More information about the department is available on the website http://www.ece.ust.hk.

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

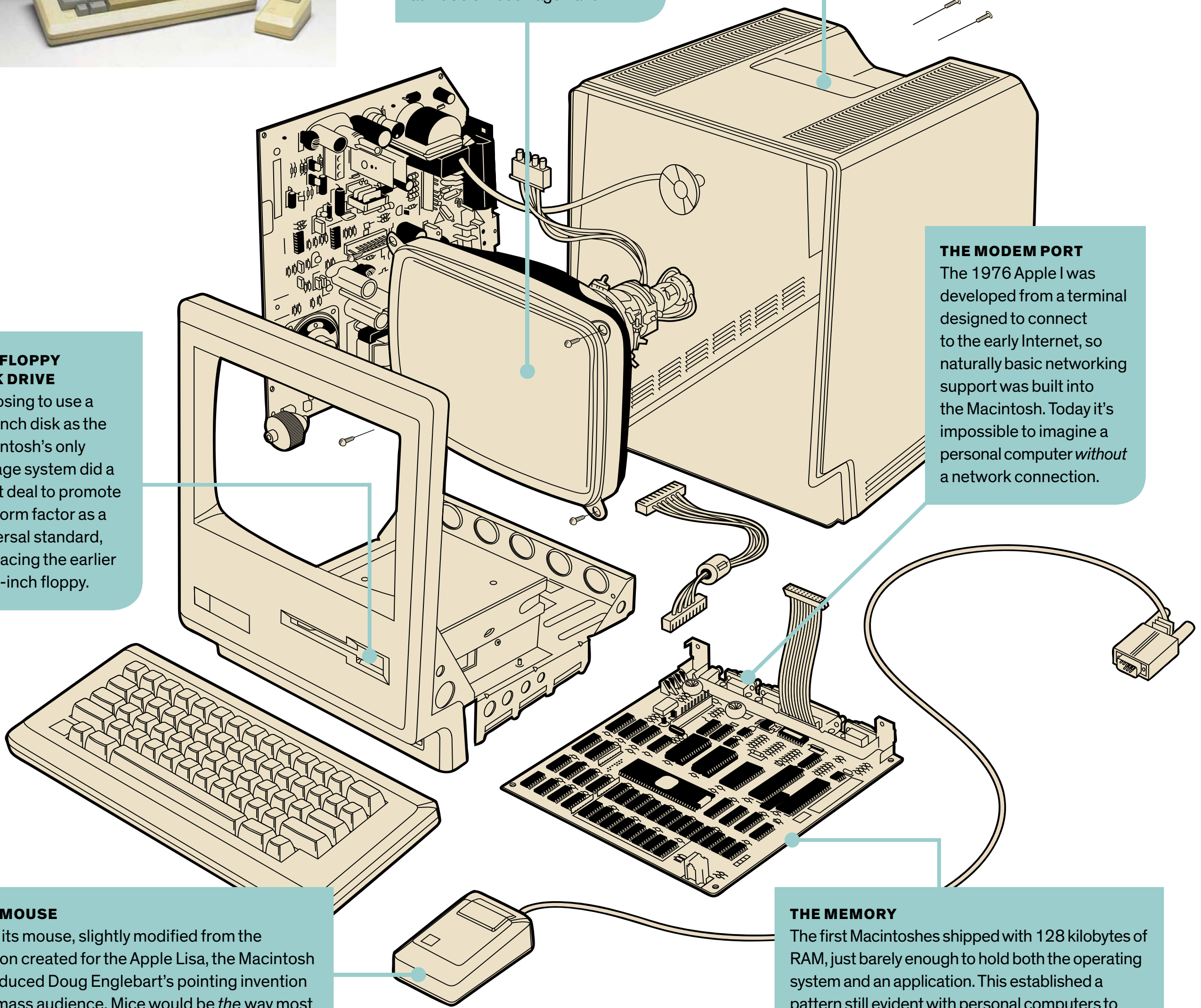
DATAFLOW_

30 YEARS OF THE MAC

THE INFLUENCE OF THE ORIGINAL MACINTOSH IS STILL FELT TODAY

Famously introduced by a Super Bowl TV ad directed by Ridley Scott, the first Macintosh went on sale in January 1984. Drawing on development efforts for the Xerox Alto and Apple's own ill-fated Lisa computer, the Macintosh offered the first commercially successful graphical user interface. But that's not the only innovation packed into the case. **—STEPHEN CASS**

SSPL/GETTY IMAGES



THE SCREEN
The resolution of the 9-inch monochrome screen was 72 pixels per inch. Matching the 72-points-per-inch standard used by typographers, the Macintosh smoothed the way for revolutionary desktop publishing software such as 1985's Aldus PageMaker.

THE HANDLE
Molding a handle directly into the case signaled that the Macintosh needn't stay in one place. A similar physical cue was used with the iPad, whose curved back encouraged people to pick it up.

THE MODEM PORT
The 1976 Apple I was developed from a terminal designed to connect to the early Internet, so naturally basic networking support was built into the Macintosh. Today it's impossible to imagine a personal computer *without* a network connection.

THE FLOPPY DISK DRIVE
Choosing to use a 3.5-inch disk as the Macintosh's only storage system did a great deal to promote this form factor as a universal standard, displacing the earlier 5.25-inch floppy.

THE MOUSE
With its mouse, slightly modified from the version created for the Apple Lisa, the Macintosh introduced Doug Englebart's pointing invention to a mass audience. Mice would be *the* way most people would navigate software for 25 years—until Apple introduced the first widely adopted touch-screen interfaces with its mobile devices.

THE MEMORY
The first Macintoshes shipped with 128 kilobytes of RAM, just barely enough to hold both the operating system and an application. This established a pattern still evident with personal computers to this day: Nobody ever has enough memory.

ILLUSTRATION BY Gary Booth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