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# TOP 10 TECH CARS


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**START IT UP:** Sleek lines hide even sleeker engineering inside this year's crop of high-tech cars [top]; Amor Nadji is helping build a particle accelerator in Jordan [bottom left]; Hiroshi Ishiguro watches over his robot replica.

*COVER: MERCEDES-BENZ*

*THIS PAGE, CLOCKWISE FROM TOP: AUDI; MAKOTO ISHIDA; JOSEPH ZAKARIAN*

COVER STORY

volume 47 number 4 north american

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**BE QUIET!** Android teacher Saya, developed at the Tokyo University of Science, can call roll, conduct a lecture, and scold, too.

*PHOTOS: TOP: ITSUO INOUYE/AP PHOTO; BOTTOM: FRANCESCO FERORELLI*

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AVAILABLE 1 APRIL

## ODE TO THE UNCANNY VALLEY

Are humanlike robots creepy? In 1970, Japanese roboticist Masahiro Mori proposed that although we may feel more comfortable with robots that resemble humans, when lifelike appearance is approached but not attained our reaction shifts from empathy to revulsion. This supposed descent into creepiness became known as the "uncanny valley," and despite the notoriety of the idea in popular culture, it remains a controversial notion in robotics circles. Is it a valid scientific conjecture or just pseudoscience? Watch our slideshow, which features some of the most striking anthropomorphic robots, lifelike mannequins, and computer-generated characters ever created, and decide for yourself: http://spectrum.ieee.org/uncannyvalley.

ONLINE FEATURE

### HOMEMADE SYNTHESIZER

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When Jay Dilisio, a musician and artist from Baltimore, became interested in synthesizer-based music from the 1970s, he realized he couldn't afford actual vintage analog synths. So he built his own. See and hear Dilisio's creations at http://spectrum.ieee.org/synthesizer.



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**CYBER VULNERABILITIES IN INDUSTRY**
The systems most vulnerable to a cyberattack aren't those that house your identity or passwords; they're the industrial control systems that run power plants, manufacturing facilities, and oil refineries. That's according to cybersecurity expert Joseph Weiss, author of two IEEE Expert Now tutorials on how to protect these systems.

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# back story


COURTESY OF ANNE-MARIE CORLEY

## Gone in 22 Hours

ARRIVING ON a snowy winter's day in gray Vancouver, *IEEE Spectrum* journalism intern Anne-Marie Corley was nonetheless full of anticipation. She had jetted across the continent to be among the first journalists to drive Nissan's highly anticipated pure-electric car, the Leaf. She was on assignment for our "Top 10 Tech Cars" (in this issue), and she'd be in Vancouver for a grand total of 22 hours.

Then she got a look at the car. It wasn't the sleek e-speedster that will go on sale later this year in Japan, the United States, and Europe, but rather a "test mule," with the guts of a Leaf and the body of a dowdy Versa. But that didn't take away from the fun of driving it. A Nissan observer riding shotgun didn't flinch as Corley stomped on the gas (whoops, electricity!) and slammed on the brakes while zipping around the test course. But when he saw her sneaking back to the track to try for a fourth spin, he greeted her with a shake of the head and said, "Oh, you again?"

Having piloted a Toyota Prius across the southwestern United States and sped a pint-size Daimler Smart car down the German autobahn, Corley had felt the difference between those cars and regular sedans. So it surprised her that the Leaf "felt just like driving a normal car."

Unfortunately, because the car wasn't complete on the inside, she didn't get to try out the space-age controller that replaces the gearshift. And although she got to drive the car into the garage for its lunch break (sandwiches for press, electrons for the Leaf), no amount of finagling kept Nissan engineers from shooing her away before they plugged in the EV. "It's not the real one anyway," they told her. So she'll have to wait with the rest of us to take a peek at its charging hardware.

She did manage to squeeze in a few more test runs before being left behind by the press van. Then she got out of town just in time for her flight—and just before the snow hit. ❑

CITING ARTICLES IN IEEE SPECTRUM

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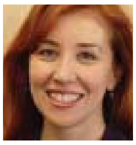
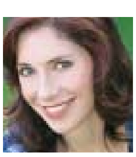


**SIGRID CLOSE** first agreed to write "Space Invaders" [p. 38] nearly three years ago, when, as a Los Alamos National Laboratory researcher, she was profiled for our 2008 Dream Jobs issue. But after that issue hit the stands, her career went nuclear: She got a tenure-track position at Stanford and starred in a forthcoming TV reality show called "Asteroid Hunter," among other things. Once the dust settled, Close finally had time to write about her passion: the space dust that can demolish entire satellites.

**MAKOTO ISHIDA** did the featured photography for "The Man Who Made a Copy of Himself" [p. 44]. He intended to make the robot look alive, but the moment he walked into Hiroshi Ishiguro's lab, he realized that wouldn't be an issue. "I thought Dr. Ishiguro himself was sitting in the chair, but it turned out to be the twin robot. It's that real from a distance," Ishida says. The shoot was still challenging, because the two men had to manually pose the robot joint by joint, and because its gaze couldn't follow the camera, they had to adjust their positions while the robot sat still. Ishida noted that Ishiguro had lost some weight in the two years since he created his twin, but the robot, of course, hadn't changed a bit.



**SUSAN KARLIN** first saw a preview of the *Hubble 3D* movie, covered in Geek Life [p. 26], at an IMAX *Avatar* screening in LA. The astronauts' feet looked like they were coming straight out into the theater, she recalls, and there was "an audible gasp" in the audience. "I remember thinking, 'That's the movie I want to see,'" Karlin says. She's a self-proclaimed space geek—as a kid, she had a poster of the Apollo 11 crew on her wall.

**JAMES TURNER** designed his own printed circuit board and then had it custom-fabricated for less than US $20, a project he describes in "Board Certified" [p. 24]. His 15-year-old son, Daniel, has also caught the DIY bug and occasionally assists Turner in brainstorming his designs.

**LAWRENCE ULRICH,** who test-drove two cars for "Top 10 Tech Cars" [p. 28], came to auto journalism by an unorthodox route: rock music. The native Detroiter worked in the 1980s as a rock musician, playing keyboard as far afield as Europe before becoming a business writer in the early 1990s, then a car writer. He lives in Brooklyn, N.Y., and regularly writes for *The New York Times* and *Automobile*.

**JOHN VOELCKER,** an *IEEE Spectrum* contributing editor, went to Vista, Calif., to try out the all-electric, egg-shaped Aptera 2e for "Top 10 Tech Cars" [p. 28]. A connoisseur of vintage British cars such as the Morris Minor and the Riley One-Point-Five, Voelcker sold his first automotive article at age 14. He has also written for *Popular Science* and *Wired*.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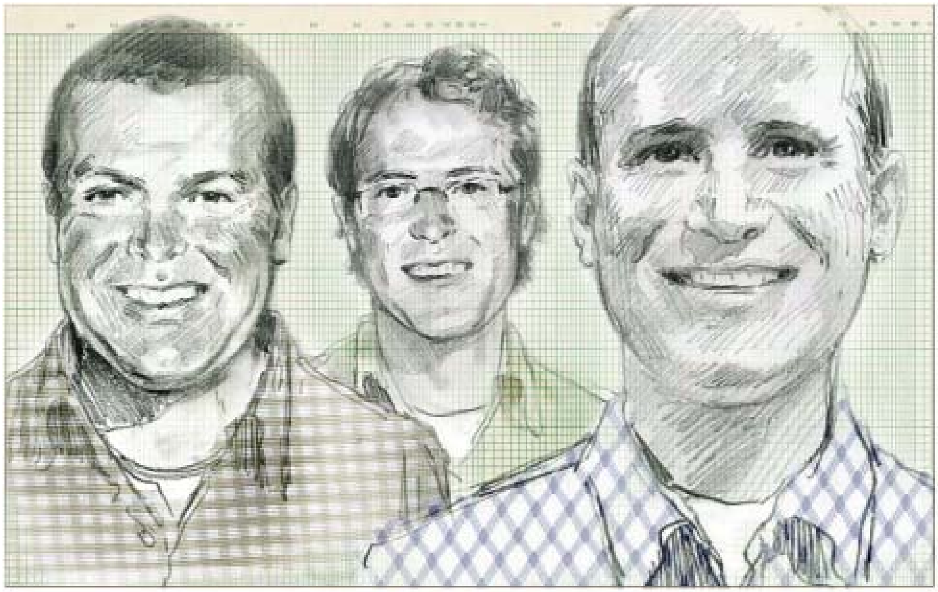
CLOCKWISE FROM TOP LEFT: STANFORD UNIVERSITY; JAMES TURNER; RANDI SILBERMAN (2); CARIN BAER; MAKOTO ISHIDA

spectral lines

# Tesla Tragedy: How Much Engineers Matter



From left, Doug Bourn, Andrew Ingram, and Brian Finn.

JOSEPH ADOLPHE

IT'S A small valley," I heard people saying over and over as, like other Palo Altans, I took to the streets, ostensibly looking for power, Internet access, and hot coffee, but really just wanting to be out among people. It was too strange to be home alone in a cold, silent, and dark office. Just before 8 a.m. on Wednesday, 17 February, the entire town—except a few random traffic lights—lost power when a small airplane crashed into a transmission tower.

At first, while we'd heard there'd been a plane crash, we didn't feel particularly connected to the crash itself; we were more concerned about the massive power outage and how we could possibly get through the day without the Internet.

Then we heard that the plane was carrying three Tesla Motors employees. Whoa. Tesla is one of our own, a Silicon Valley start-up launched with some of the fortune created by Internet company PayPal—and a company that *IEEE Spectrum* has followed very closely from the very beginning. And if we didn't know the Tesla employees on board that plane, we certainly all knew at least one person who did. Forget six degrees of separation—the valley is a lot smaller than that. And the silent day without power no longer felt like a sudden holiday. It was a day of mourning.

*A version of this article appeared in IEEE Spectrum Online's Tech Talk blog on 19 February.*

Doug Bourn, Brian Finn, and Andrew Ingram died in the crash. Bourn, 56, was piloting the plane. He was a senior electrical engineer at Tesla and an important part of the team that developed the power train for the Tesla Roadster. He liked to explain things—whether it was the ins and outs of the Roadster to a local group of engineers or how to solve a robotics problem to a group of high school girls. Bourn, an IEEE member, spoke regularly at IEEE and American Society of Mechanical Engineers events and was a volunteer coach for the robotics team at Castilleja High School, in Palo Alto. He also taught flying. Before joining Tesla, Bourn spent 10 years at Ideo, the independent design firm behind the original Apple mouse and the Palm Treo.

Finn, 42, was senior interactive electronics manager at Tesla, working on an interactive touch screen for the next-generation car. An IEEE member, Finn previously worked at the Volkswagen Electronics Research Laboratory in Palo Alto; he loved skiing and playing the guitar.

Ingram, who celebrated his 31st birthday two days before the crash, worked at Tesla as an electrical engineering generalist. Coming off his previous post at Dolby Laboratories, he was passionate about audio, but according to Tesla's blog, he was "eager to lend a hand wherever it was needed, from marketing to manufacturing." In his free time he rowed with a local crew team.

The night before the crash, Bourn worked with the girls at Castilleja in a final push to complete their robot; they had only a few days before it had to be shipped to a competition in Oregon. The team worked on after the crash, spending the day fixing a few things and soldering. One team member posted in a blog: "I remember when [Doug] taught me how to solder. I'm an excellent solderer now—I learned from the best. I think it's appropriate that I spent today soldering, and even better, teaching other people how to solder. We all wore our safety glasses, and our soldering was wonderful." Their season continues, but, their Web site notes, Bourn's loss will be felt: "Doug was a calming force for the team through all of their ups and downs and was always present at local competitions to cheer the team on."

There's an engineering stereotype—engineers just do their work, oblivious to the rest of the world around them—but if you think about what's been lost with the deaths of these three men, you will know it's not true. —TEKLA S. PERRY

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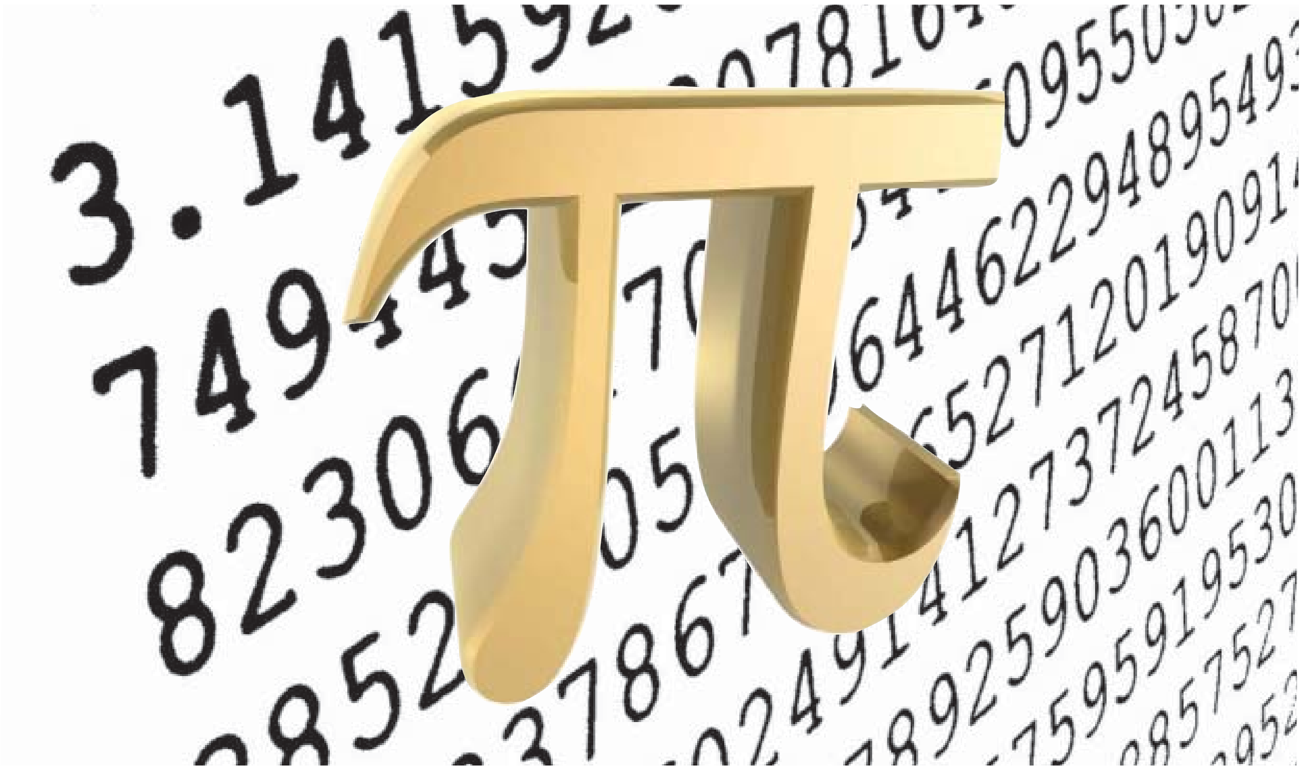

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## DREAM ON

I CAN RELATE to Catherine Mohr's satisfying career in medical device design ["Robodoc," Dream Jobs, February], having worked in this field for 35 years. I can also appreciate the value of her work, having had da Vinci robotic surgery. However, Mohr's motivation to move from green automotive design to medical products needs a reality check. I have made a good living riding the medical-device-development gravy train, but a train wreck is fast approaching.

Mohr says she was frustrated by the "huge entrenched political, philosophical problems lined up" against the commercialization of electric cars. But she fails to consider that a wonderful green automotive design must also be one that makes economic sense to the consumer. Otherwise it won't be produced, even if it might save the world from the mythical carbon dioxide threat.

Conversely, medical devices have been very heavily subsidized by the U.S. government, in the form of Medicare, Medicaid, tax-deductible insurance premiums, and so on. The consumer is usually isolated from the economic decisions by insurance and so doesn't have to consider economic value. I have no idea how much my robotic prostate surgery really cost.

At some point the nation's health-care costs will force policies under which medical-device and drug developers will have to recognize the market realities that car manufacturers have always had to face.

PETER STAATS
*IEEE Member*
*Loveland, Ohio*

## POWER YOUR WAY

ELECTRIC VEHICLES will indeed add additional load to the power grid ["Speed Bumps Ahead for Electric-Vehicle Charging," Update, January]. But there is a simple, win-win solution to this problem: Use off-grid charging. A small natural-gas-powered engine spinning a 6-kilowatt generator with both 115- and 240-volt output could be used to charge an electric vehicle with no connection whatsoever to the grid. Such engines already exist for emergency power backup but are pricey; a mass-produced unit specifically designed for vehicle charging might bring the price down.

WILLIAM C. BLACKWELL
*IEEE Life Member*
*Richardson, Texas*

## EYES ON THE PRIZE

SURPRISINGLY, the controversy over this year's Nobel Prize in Physics goes on ["The Nobel Prize and Its Discontents," Update, December]: Was Eugene Gordon the real inventor of the charge-coupled device? Why give the physics prize to new technology? Did the committee get the citation wrong?

Gordon's own testimony makes it clear that he did *not* invent the CCD. In his account, posted on IEEE Spectrum Online six months ago, he wrote, "I handed [George] Smith the idea of a silicon shift register run by a 3-phase clock, i.e., the initial CCD invention." [See http://spectrum.ieee.org/tech-talk/semiconductors/devices/nobel-controversy-who-deserves-credit-for-inventing-the-ccd.] Shift registers made in various technologies had been around since the beginning of computers. It was well known that shift registers required the use of a three-phase clock to move charge in one direction. A vague suggestion that such shift registers might be useful in an imaging chip is a far cry from inventing the CCD.

Does technology have a place in physics? Technology has always been the basis for experimental science: Galileo's telescope and Hooke's microscope depended on glass technology. Giving the Nobel Prize in Physics to the modern successors of the optical technologists makes all the sense in the world.

Was it wrong for the Nobel committee to refer to the CCD's imaging applications in the awards citation? I was a member of Nobel Prize–winner Willard Boyle's division at Bell Labs when the CCD work was being done, so I can testify that it was obvious at the outset that the CCD could support imaging. Its greatest impact has been on that field, so it would have been ridiculous *not* to refer to it in the citation. Mike Tompsett quite rightly got the first patent on an imaging application of the CCD, but it was a derivative idea, not part of the seminal invention.

BERNARD T. MURPHY
*IEEE Life Fellow*
*Mertztown, Penn.*

# update

more online at spectrum.ieee.org

# U.S. Air Force Launches Secret Flying Twinkie

Military's new space plane tests unnamed powers

THE LIFTOFF of an Atlas V rocket from Cape Canaveral this month will mark one of the most secretive U.S. Air Force spaceflights in decades. Guessing the nature of the secret has become a sport among aficionados.

"This is one odd bird," military space historian Dwayne Day told *IEEE Spectrum*. "They're spending an awful lot of money for a test program that seems to have no real end user."

The 6000-kilogram, 8-meter X-37B OTV-1 is often called a flying Twinkie because of its stubby-winged shape. It was built in the Boeing Phantom Works high-security facility in Seal Beach, Calif. In the flight test, the craft is supposed to orbit Earth for several weeks, maneuver in orbit, and glide its way to a landing strip at Vandenberg Air Force Base, in California.

The smart money is betting that the flight will put to the test systems that enable satellites to protect themselves from enemy attack. The most important trick in such self-protection is determining whether you are under attack at all. A clever enemy will want the attack to seem to be a mere accident. That way he'd leave no return address.

The official description of the mission talks of demonstrating "a rapid-turnaround airborne test bed." That makes sense, but there is no sign that anyone plans to fly the vehicle ever again. Official explanations also mention putting the space plane through all its steps in orbital flight—including in-orbit maneuvering, descent and landing—while demonstrating or testing 30-odd technologies, including guidance and navigation, thermal protection and power-distribution systems, and streamlined flight, all of potential use on future vehicles. The new technologies pave the way for a

**SHORT AND SQUAT:** The X-37B is a space plane of perhaps unlovely stubbiness. It is designed to test technologies, including some the military declines to discuss.
*IMAGE: BOEING PHANTOM WORKS*



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**HELLA** A recently proposed prefix denoting the number $10^{27}$, which is three orders of magnitude larger than yotta, the next-biggest numerical prefix accepted by the International System of Units.

# update

new White House policy under which NASA is to turn over much of its ground-to-orbit transport to commercial providers.

Most of these technologies can be seen as refinements of ideas dating back to the 1960s, but one, unmentioned idea—autonomous approach—would be truly new, if speculations are correct, and it's indeed part of this spaceflight. This is the ability to identify an attacker by electromagnetic range finding and perhaps by chemical "sniffing" for effluents that an attacker might leak while trying to match up its orbit with that of the target.

**RESKINNED BIRD:** A technician adjusts panels on an early version of the X-37B. PHOTO: R. DAVIS/BOEING

To test such capabilities properly, the mission might conceivably deploy subsatellites to impersonate enemy craft, or bogies. They'd stalk the mother ship using autonomous approach techniques tested in recent years, giving it the chance to detect clues to their presence. The X-37B has a pickup-bed-size payload bay that could carry such instruments and subsatellites.

Observers suspect that the test flight may involve observations of another space vehicle. This suspicion was fanned by the announcement in late February that a Mach-5 hypersonic glider would be launched from California toward a Pacific tracking site during the X-37B's first week in orbit.

"That is a pretty interesting coincidence," noted Brian Weeden, a Montreal-based space and missile advisor for the Secure World Foundation, a private group in Superior, Colo., that monitors space technology. "Once we get more details about when they will be on orbit and can glean info about trajectories, it might get *really* interesting."

Probably the best insight into the project's purpose will come after launch, as amateur (but well-equipped) satellite watchers around the world attempt to follow its orbital flight path and course changes. (You can follow their efforts at http://satobs.org.)

The degree to which the amateurs are successful, and the effort that the X-37B managers take to evade such observation, may provide a significant clue as to just how secret—and important—this mission really is. —JAMES OBERG

## tech in sight

# A Robot in the Kitchen

ROSIE, THE ROBOT who kept house for the title family in "The Jetsons," a 1960s animated television show, has at last come alive—sort of. Before you'll see a robot slicing cucumbers in your kitchen, researchers will need to make these mechanical servants smarter. Here's how three teams are tackling this challenge. —ERICO GUIZZO


### Advanced Telecommunications Research Institute International (ATR), Kansai Science City, Japan

**WHAT:** Robovie-II can help customers locate and carry products at a Kyoto supermarket.
**HOW:** ATR researchers say that a stand-alone robot is not suited for many real-world tasks. A better approach is to use "ubiquitous network robot technology"—a mix of robots, sensors, and virtual robots. Says Hiroshi Ishiguro, an ATR Fellow, Robovie-II is eager to offer suggestions: "If you're making a broccoli salad, you might want to get some lettuce as well." If you know what's good for you. PHOTO: STR/AFP/GETTY IMAGES



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## University of Tokyo's Jouhou System Kougaku Laboratory

**WHAT:** An HRP-2 humanoid robot learns to wash dishes.
**HOW:** The researchers are using a combination of human motion-capture and video-game-style simulations to teach the robot how to handle different dishware and deal with uncertainties. "We're focusing on failure detection," says Kei Okada, a University of Tokyo professor. "So if you move a cup while the robot is trying to grasp it, the robot just recomputes its actions." That is, it won't try to grab the cup from your hands—and then vaporize you. *PHOTO: ERICO GUIZZO*

## Korea Institute of Science and Technology (KIST), Seoul

**WHAT:** Mahru, a biped humanoid, can pop a snack into the microwave and bring it to you.
**HOW:** A human wearing a sensor suit performs tasks while a motion-tracking system records the action. The robot is programmed to reproduce the tasks while adapting to changes in the space, such as a displaced chair. "Robots that operate in human environments need to move like humans," says Bum-Jae You, head of KIST's Cognitive Robotics Center. Mahru also performs some dance moves like a pro.
*PHOTO: YURIKO NAKAO/REUTERS*

# Too Big to Hack

## To keep cyberspace secure, must governments regulate mighty Google?

EARLY THIS YEAR, when the search giant Google fell victim to hackers in China, a lot of wild-eyed speculation began. Will Google carry out its threat to pull out of China? Could Google, like Microsoft before it, face crippling antitrust lawsuits? Might the company end up a semiregulated public utility? And, given the monopoly status of such a utility, would Google quietly enjoy such a future?

Probably not, maybe, no, and no, say cybersecurity and antitrust experts.

It all began in January, when Google said it had recently detected hacks on its Gmail system from China. *The New York Times* later reported that the attacks originated at two educational institutions. On 23 February, the Chinese government labeled the allegations "groundless."

The attack involved a security breach that released malicious code inside one of Google's firewalls. Such attacks, called spear phishing, may arrive as spam or blog links that lure users inside—in this case, Google's secure networks—to visit seemingly innocent Web sites that off-load viruses or other malware onto the user's computer.

"No one knows the payload of what that malicious code was supposed to do, other than access Gmail records—and figure out who was a threat to the government," says Jeffery Payne, CEO of Fairfax, Va.–based computer security firm Coveros. "But they also seemed to be digging into and getting the source code for Google's intellectual property."

The problem goes far beyond the Chinese market, Payne says. The hack undercut the trust necessary for the adoption of all of Google's applications, notably e-mail, word processing, spreadsheets, and now social networking. One large financial service organization, the name of which Payne declined to provide, had been planning to shift more of its IT infrastructure over to Google apps. But "when this [Google hack] happened, they immediately started reevaluating," he says.

Mark Kadrich, CEO of consulting firm The Security Consortium, in San Jose, Calif., says he thinks the attack was at its core about market share.

"My hunch is this attack directly targeted intellectual property Google has—to help Baidu be more competitive," says Kadrich. Baidu is a search engine based in China.

Google has turned to spy agencies like the National Security Agency, not as part of some Big Brother conspiracy but rather because countering cyberattacks is the agency's specialty.

And what of the argument for regulation, which claims that information is a public resource like water or electricity and that its management and flow therefore need to be treated as a public utility?

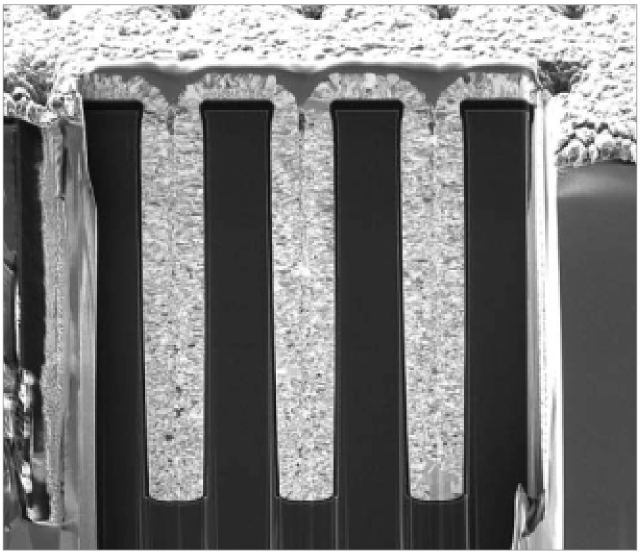
The analogy doesn't work, says Payne, because using water and electricity requires installing and maintaining the pipes and wires coming into every home. Such service requires government assistance to function.

"We don't have that problem on the Internet," Payne says. "Google doesn't own the standards for the Internet or for how information is transferred." However, he adds, "they will come under antitrust scrutiny. They're just too big and too successful not to."

*—Mark Anderson*

**1.26 MILLISECONDS** The time by which the length of a day is estimated to have been shortened by the recent earthquake in Chile, which at 8.8 on the Richter scale ranks as the seventh strongest quake ever recorded.

# update



**VERTICALLY CHALLENGED:** Copper "vias" connect silicon dies stacked in a deck.
*IMAGE: IMEC*

## Chipmakers Bet on a Stacked Deck

Three-dimensional packaging promises smaller, smarter gadgets

IMAGINE THAT your favorite aunt lies sick on the other side of town. Rather than brave the highways to visit her, you move her into your apartment building and just ride the elevator up.

Chipmakers are applying the same strategy to get around the biggest speed bump in microelectronics—the distance between dies. Instead of wiring chips to one another in two dimensions, in which the input/output plugs are spaced some 200 micrometers apart, engineers plan to link them in a 3-D stack, using copper interconnects 10 µm apart—vertically. The interconnects, called through-silicon vias (TSVs), might be said to resemble elevator shafts.

The hope is that TSVs will enable the industry to keep increasing the capabilities of smartphones and other gadgets while making them tinier, even as transistor densities rise at ever more sluggish rates, says Pol Marchal, a principal scientist of 3-D integration at European microelectronics R&D center Imec.

To be sure, there are still a few problems. At February's IEEE International Solid-State Circuits Conference, Imec engineers presented some key design challenges that must be overcome before TSVs can be widely used.

The first challenge is size. The handful of products that now contain TSVs—such as some image sensors and dynamic RAM stacks—use relatively hefty chunks of metal, typically about 100 µm wide. But that's not good for integrating disparate devices, such as logic and memory, because the TSVs themselves take up too much real estate. However, Imec's work has demonstrated that you can make TSVs 5 µm wide, which allows for squeezing more TSVs—and more transistors—on each layer.

Another challenge is the mechanical stress you get during the cooling stage of processing, when the copper TSVs contract faster than their silicon bedding does. That stress can hinder transistor performance. Depending on a device's application, designers will have to take into account how much stress a system can handle and how far apart the TSVs should be to reduce the stress in the silicon, Marchal says.

One problem in buildings is that as they get taller, they require so many elevator shafts that there's no more interior room for anything else. For stacked chips, too, there are height limits, particularly for consumer devices where the whole package must be minute. For these applications, the stack height is limited to 300 µm, or about 3 or 4 tiers, Marchal says. Stacks could grow to 16 tiers before hitting reliability barriers or delivering power unevenly throughout the stack.

Also, the proximity of TSVs to transistors on the chip can alter performance values, such as threshold voltage and drive current. Designers will therefore have to introduce "keep out" areas where there are no devices. For instance, in a digital-to-analog converter made using the common 65-nanometer lithography process, each analog component must sit tens of micrometers from a via to avoid reducing performance more than 0.05 percent, which is essential in a highly accurate converter.

So 3-D chip designers will have to carefully balance the cost of the altered architecture that TSVs require with the benefit of tighter integration. Otherwise, chips with TSVs might turn out to be just as costly in terms of wasted space or poor performance as the multiple 2-D chips they are about to replace.

Nevertheless, Marchal says, "the industry pull for this technology is big," and TSVs should be common in chips by 2012 or 2013. In the meantime, Imec is working with electronic design automation firms to model trade-offs among performance, efficiency, and a compact 3-D floor plan.

—ANNE-MARIE CORLEY

*A version of this article ran online in February 2010.*

# Good to the Last Volt

An Indian EV manufacturer may just have the cure for range anxiety

**ENOUGH TO LIMP HOME:** The Daimler Smart ForTwo electric car lets you get below the red line. *PHOTOS: DAIMLER*

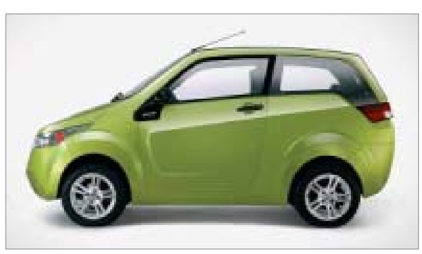
BANK CARDS let you overdraw your account when you must on the understanding that you'll pay it back when you can. If you could do the same for your electric car by overdrawing the battery, it'd sure alleviate range anxiety—the fear that you might get stranded far from an electric plug.

Overdrawing your battery simply means taking advantage of a power reserve that today's control systems deliberately build in to preserve the electrodes and thus extend battery life. The reserve can amount to 30 percent of the battery's capacity. In the Chevrolet Volt, a plug-in hybrid that will use a gasoline engine as a range extender—and thus can afford to protect the battery's life very carefully—the pure-electric reserve will reportedly come to 40 percent.

Reva Electric Car Co., based in Bangalore, India, and the world's leader in electric vehicle (EV) sales, is parlaying data from the 135 million kilometers (84 million miles) logged by its EVs into an expert system that can give drivers an extra 10 km. The system, called REVive, uses remote communications to enable the system to determine how much extra charge can be accessed without doing harm.

"This is really a very complex problem," says Chetan Maini, Reva's chief technology officer. "This is not something that you could fix in an algorithm that meets all situations."

When REVive receives a text or voice message from the driver, it remotely accesses the vehicle's three-year store of data on such crucial parameters as the battery's age, the number of charge cycles, whether it's been scorching in Mumbai or freeze-thawing in Oslo, and how aggressively the car has been driven. REVive feeds that data to algorithms, resets the range gauge, and puts the car in a "limp mode" akin to that of a laptop on a power-saving regime.



**DOUBLY GREEN:** The Reva NXR runs on volts alone.
*PHOTO: REVA ELECTRIC CAR CO.*

REVive will be a standard feature in future Reva EVs, starting with a lithium-ion-battery version of its NXR subcompact to be released later this year in India and Europe. The car comes with an already substantial 160-km range, double that of the carmaker's EVs powered by traditional lead-acid batteries.

Reva's solution has merit, according to Andrew Burke, a research engineer and battery expert at the Institute of Transportation Systems, at the University of California, Davis. He says that although deep discharges are in general bad for battery life, they can be allowed once in a while without causing real damage, given that the extra range is profoundly reassuring to customers.

Burke was himself reassured a decade ago, when he drove an electric car that Honda marketed briefly under California's zero-emissions vehicle program. On three or four occasions he miscalculated how far he'd be driving but nevertheless made it home, thanks to the car's limp mode. Inching along was no fun, recalls Burke, but "I was happy to get home *any* way."

Limp mode is a feature on the updated electric-drive version of the Smart ForTwo, which Daimler began test-leasing in December, according to Pitt Moos, the vehicle's product manager. But Moos sees no need to proceed further to the "hassle" of a system such as REVive, betting instead that time and consumer experience will dispel range anxiety. "People who are very scared of getting stopped by zero percent [state of charge] won't buy or lease battery EVs," says Moos. "Those who [do] will learn the cars and feel perfectly safe after a while. They will pass their experience along, and the market will grow."

Still, if REVive can assuage range anxiety, it will boost the sales of the Reva, push other manufacturers into similar battery-management schemes, and expand the EV market that much faster.

—PETER FAIRLEY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update

# Reverse Engineering the Human Face

## Weta Digital lifts the veil on its digital special effects



**FURIOUS FACE:** *Avatar* actress Zoe Saldana playing Neytiri, using Weta's motion-capture technology.
IMAGES: TOP: WETA; BOTTOM: MARK FELLMAN

If *Avatar* is the bright future of cinema, a great deal of that dazzle is going to come from Weta Digital, the firm that created most of the movie's Oscar-winning visual effects.

This past January, *IEEE Spectrum* visited the company's headquarters in a homey suburb of Wellington, New Zealand, where key officials spoke at length about cinema after *Avatar*. There were also a few tantalizing insights into Weta's work for its next blockbuster, *The Adventures of Tintin: The Secret of the Unicorn*.

Weta's specialty is motion capture, which relies on sophisticated software and hardware to transfer an actor's body movements and facial expressions to an animated character. The actor wears a black suit with light-colored dots; to detect his movement, optical systems track those dots.

For *Avatar*, Weta pushed the state of the art. First, it employed head-mounted cameras, worn by the actors, that tracked dots on their faces. The use of the camera greatly increased the range of emotions that could be transferred to the faces of the animated characters, enabling audiences to relate more closely to the computer-generated creatures.

Second, the Weta system enabled director James Cameron to see the results of motion capture essentially in real time. As the actors performed, Cameron was able to look at a screen near his camera and see, in place of actors in black suits, a slightly cruder version of the blue computer-generated space aliens that audiences would see.

The most complicated software challenge was coping with the essentially unlimited variety of expressions that a human face can convey. The solution, according to Weta specialist Luca Fascione, depended on identifying several hundred "key poses"—fundamental facial expressions.

"The computer says, 'I want 30 percent of this one expression and 50 percent of this other expression,' " Fascione explains. "And then the rigging and the machinery behind the puppeteering [character animation] system is able to make the face express that particular emotion."

Meanwhile, as part of a push to advance the state of the art for the highly anticipated *Tintin* movie, a team at Weta is helping to devise a new generation of motion-capture software built on a foundation of physiological principles. The group is working on software that incorporates the underlying anatomy of the face.

"What I'm trying to do," says team leader Mark Sagar, "is reverse engineer all the expressions in the human face so we can understand the mechanical basis of, say, what makes a smile have a dimple. What makes the creases in a face when it smiles? It all depends on the anatomical structure of the face, the substructures beneath the facial tissue: the ligaments, the fat, the muscles, how the muscles are laid out in 3-D space."

On a Tuesday morning this past January, in an open, darkened work area at Weta, animation specialists peered at screens showing the face of either Thomson or Thompson, one of the bumbling doppelgänger detectives from the Tintin comics. As the lips and chin of the animated head moved, bulges appeared and disappeared in the skin around the mouth and cheeks, mimicking a face with startling realism.

The *Tintin* film is a joint effort between Steven Spielberg and Peter Jackson (Jackson cofounded Weta in 1993), with a budget rumored to be around US $135 million, well under *Avatar*'s reported $300 million to $400 million. *Tintin* is already the subject of sporadic movieland buzz because it's understood to be a labor of love for Spielberg and Jackson. Both have professed deep affection for the comic-book series about a globe-trotting boy reporter, his wirehaired fox terrier, and his choleric seafaring friend. The movie, which is to be the first of a three-movie series, is scheduled for release in late 2011.

"Working with such directors as James Cameron, Steven Spielberg, or Peter Jackson, there is never a known path that we're going to go through," says Weta R&D director Sebastian Sylwan. "It's always trying to push the boundaries of what can be delivered and how a better story can be told." —GLENN ZORPETTE



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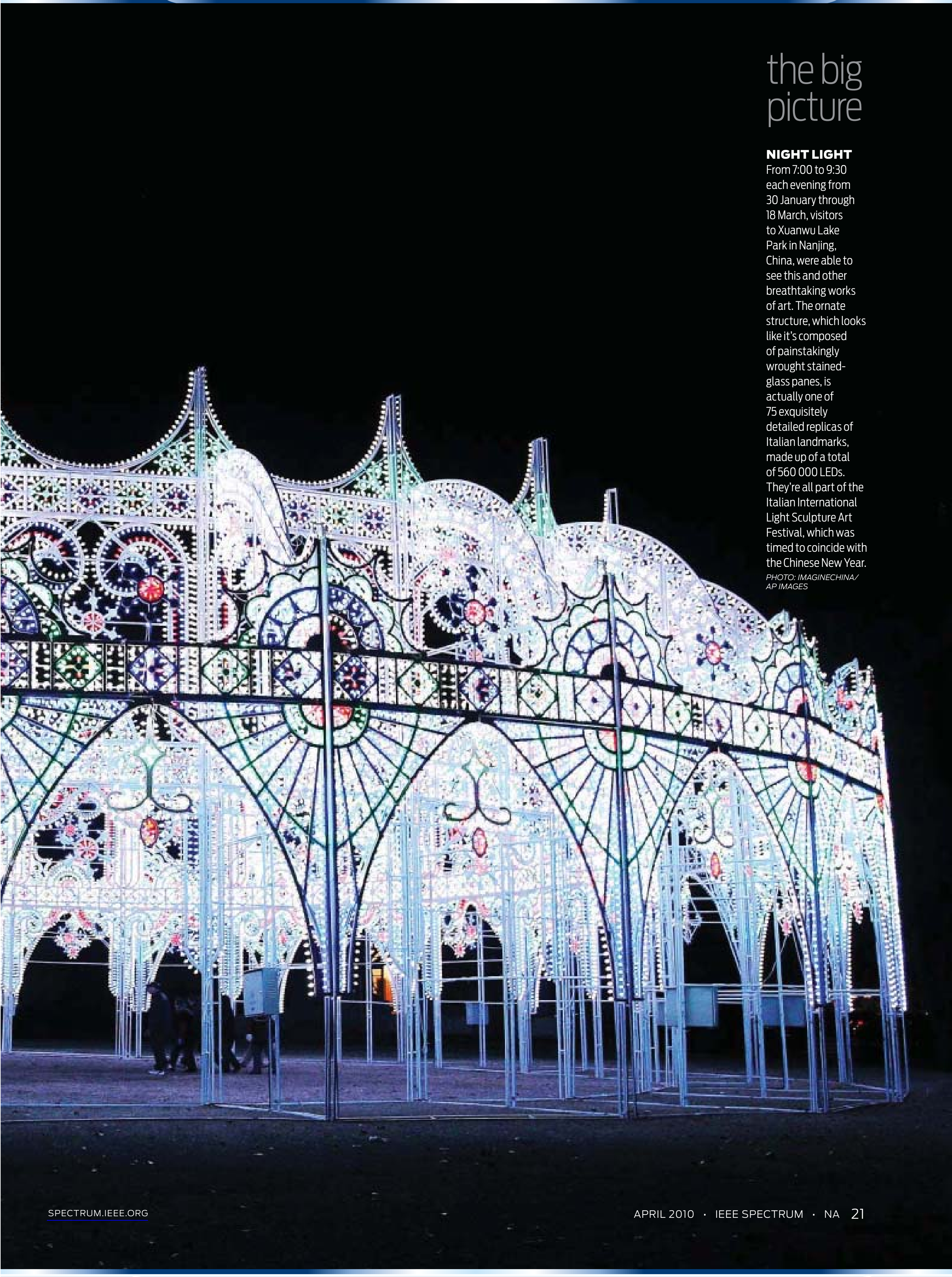

# the big picture

**NIGHT LIGHT**
From 7:00 to 9:30 each evening from 30 January through 18 March, visitors to Xuanwu Lake Park in Nanjing, China, were able to see this and other breathtaking works of art. The ornate structure, which looks like it's composed of painstakingly wrought stained-glass panes, is actually one of 75 exquisitely detailed replicas of Italian landmarks, made up of a total of 560 000 LEDs. They're all part of the Italian International Light Sculpture Art Festival, which was timed to coincide with the Chinese New Year.

*PHOTO: IMAGINECHINA/AP IMAGES*



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# tools & toys

**Olympus E-P2**
US $1100
http://www.olympusamerica.com


## LITTLE BIG CAMERAS

### Your next digital camera may adhere to a standard you've never heard of: Micro Four Thirds

LAUNCHING a new consumer electronics category is a risky business, and it doesn't help when it's squeezed into the no-man's-land between two other categories. Tablet computers, for example, are awkwardly situated north of smartphones in size and south of notebooks in performance.

With November's launch of the Olympus E-P2, the population of the no-man's-land between the top end of point-and-shooters and the low end of digital single-lens reflex (DSLR) cameras reached five models. But there's little indication that the public understands the new category any better than it did in August 2008, when Panasonic and Olympus launched their first Micro Four Thirds cameras.

That's the cumbersome name the industry uses for these so-called pro-sumer cameras: *Micro* represents their smaller footprint compared to that of DSLRs, and the digits stand for the 4:3 aspect ratio of their midsize detectors. A blend of *professional* and *consumer*, "pro-sumer" identifies what manufacturers fervently hope is a growing category of more feature-laden (and pricey) cameras and interchangeable lenses in a postfilm world.

According to a spokesman for the Consumer Electronics Association, only 6 percent of the 32 million cameras sold last year were DSLRs, and Micro Four Thirds sales were so low that the association didn't even bother to track them.

If the new category lacks consumer acceptance, at least it has a standard to lean on. In the late 1990s, Olympus, Panasonic, and five other camera and lens companies created a digital photo standard called Four Thirds, around which both camera bodies and detachable lenses could be created.

"A lot of manufacturers were morphing 35-mm cameras into digital designs," says Richard Pelkowski, a digital-camera product manager at Olympus. "We felt that we really needed a clean slate. We wanted to go with designs that are smaller and more compact." He says the Four Thirds' charge-coupled-device footprint was designed to maximize image quality, minimize size, and remove any 35-mm film legacy from digital photography. Four Thirds cameras also have shorter focal lengths and thus smaller lenses: Their 25-mm lenses are equivalent to 50-mm lenses on a standard SLR. According to the Four Thirds consortium's Web site (http://www.four-thirds.org), there are more than 40 different lenses on the market, from Olympus's 8-mm fish-eye to Sigma's 50- to 500-mm supertelephoto 10x zoom.

Micro Four Thirds eliminates the SLR mirror box, viewfinder, and, says Pelkowski, "a lot of internal components that are from analog days." Losing the mirror box is a big step: Without a separate through-the-lens viewfinder, simpler, faster, smaller cameras are possible. Micro Four Thirds cameras are between three-quarters and two-thirds the size of DSLRs but retain much of their higher-end cousins' image quality and low-light capability—or at least that's the idea. And some of the pros find the format promising.

Consider J. Dennis Thomas, a professional photographer in Austin, Texas. He uses DSLRs for his in-studio work but grabs a 12-megapixel Olympus E-P1 Micro Four Thirds shooter when he heads out for a hike or a walk downtown. "You can stick it right in your pocket," he says, and despite the E-P1's smaller footprint, "it does have a much larger sensor than your basic compact camera. That's going to give it a higher signal-to-noise ratio and a little more control over depth of field."

The smaller footprint allows Thomas's street shooting to be more candid. When he aims his DSLR, people often ask him which newspaper their pictures will be appearing in. But with his Micro Four Thirds, he says, "my eyeball's not up to the camera. It just looks like I'm pointing it in a general direction."

Jay Kinghorn, a Salt Lake City professional photographer (who's sponsored, in part, by Olympus) says that Micro Four Thirds cameras have image sensors about the size of your thumb. By contrast, point-and-shoot and smartphone cameras have sensors no larger than a fingernail and "a usable range that's limited to bright daylight for optimum results." When you step up to Micro Four Thirds, he says, "you have smaller camera size, and now you're looking at very good shots in an indoor situation."

A spokesperson from Panasonic adds that its high-end Micro Four Thirds model, the Lumix GH1, has also found a niche among independent filmmakers, who have praised it for its full 1080p high-definition video. And, like any Micro Four Thirds camera, the GH1 is one small adapter away from the cornucopia of Four Thirds lenses.

I spent three weeks shooting with the Olympus EP-1 instead of a regular point-and-shoot camera. I liked the better picture quality, but the general sluggishness and noisy autofocus in HD video mode made its US $800 retail price a deal breaker. (According to Thomas, pros don't really use autofocus: "You set up the scene, focus, and shoot.") Other Micro Four Thirds cameras get better reviews, such as the GH1, but its $1500 price tag seems a lot more "pro" than "sumer."

I'd give this product category a little more time. As prices drop and performance improves, Micro Four Thirds could soon fill the gap between the camera on your cellphone and the DSLR you don't really need.

—Mark Anderson


**FOCAL POINT:** There are already more than 40 lenses for Micro Four Thirds cameras.

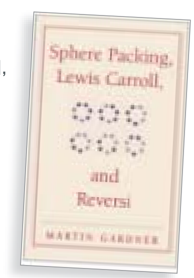
*books*

# A Garden of Mathematical Delights

## Martin Gardner's Mathematical Games columns collected in book form

"If Martin Gardner wrote a cookbook," my editor said, "we'd review it." *Sphere Packing, Lewis Carroll, and Reversi* isn't a cookbook, but it does include recipes for a couple of tricks with crackers.

For 25 years Gardner wrote the Mathematical Games column in *Scientific American*. Now Cambridge University Press is republishing them in their entirety. It will take 15 volumes. This, the third, includes 20 columns dating from 1959 to 1961, not limited to the topics of the title. Most chapters contain the original column; solutions to the problems it posed; new material, much of it up to date; and a bibliography.



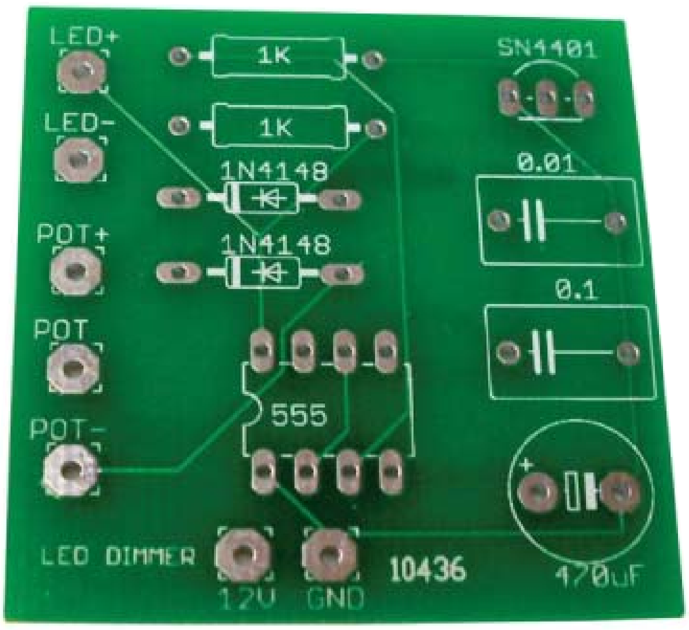

**Sphere Packing, Lewis Carroll, and Reversi**
By Martin Gardner; Cambridge University Press, 2009; 296 pp.; US $14.99, ISBN 978-0-521-74701-1 (paperback); $50.00, ISBN 978-0-521-75607-5 (hardback)

Three of the columns are collections of puzzles, while the rest concentrate on single topics, such as the binary system, pi, the four-color theorem, and board games. The chapter on sphere packing discusses not only the obvious—how densely they can be packed and how this relates to subjects like crystallography—but also the less well-known question of how sparse a rigid packing can be. Lewis Carroll gets a chapter to himself, not just about his interest in mathematics and logic but also his word games; the additional material includes some results found by computer that would not have been possible when the column was first published.

A chapter on group theory and braiding ends with the intriguing assertion that a game involving shield shapes joined by strings proves that subatomic particles can have only half or whole quanta of spin. Pure mathematicians will love a chapter on ellipses and the theorems of H.S.M. Coxeter. A discussion of the game reversi is preceded by a brief mention of the ancient Greek game of rithmomachy, which by all accounts seems the most unplayable board game ever. A chapter on mathemagic (mathematical-based magic tricks) includes the cracker tricks.

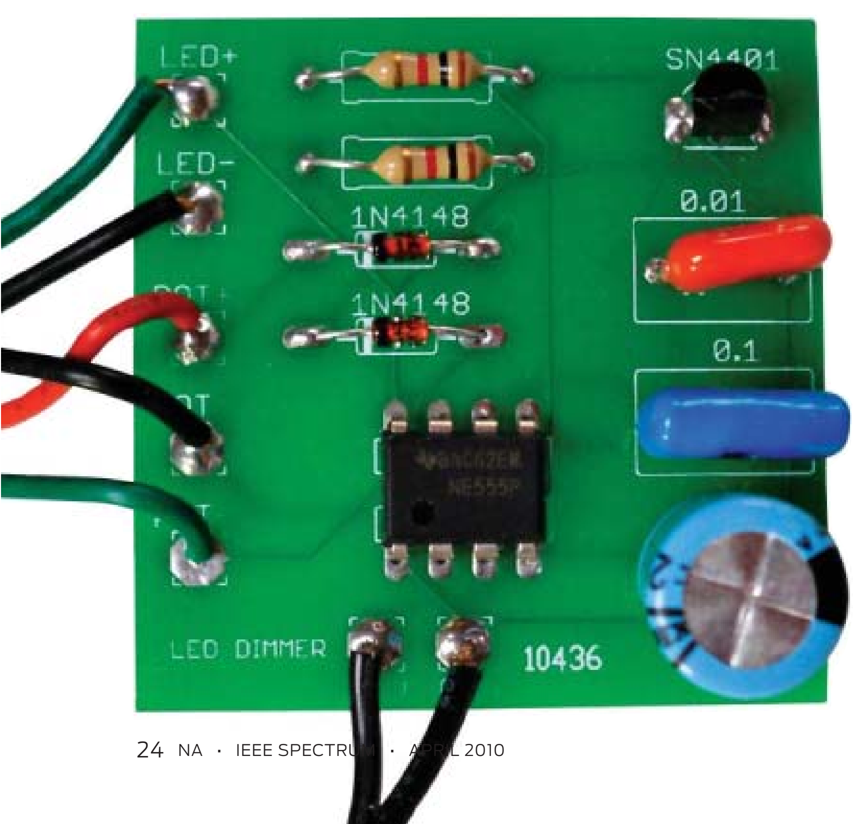
Those of us who eagerly awaited our monthly fix of Mathematical Games the first time around will welcome this update, and those who missed it will enjoy a wonderful stroll through recreational mathematics. Both sorts will surely read with pencil and paper near at hand. —*Clive Feather*

# hands on




## BOARD CERTIFIED

A custom-printed circuit board needn't break the bank




BREADBOARDING A new circuit is a key skill and an important step in many projects—especially early on, when you need to move wires around and substitute components. But that very flexibility also makes it easy to knock wires out. Eventually, if your project is a keeper, you're going to want something with a bit more permanence.

Printed circuit boards (PCBs) solve all those shortcomings. But most people don't even consider translating a one-off project into a PCB design. For one thing, PCB fabrication has traditionally been expensive, viable only in commercial quantities. (One alternative is to do it yourself with etches and silk screens, a messy and time-consuming process.) Also, there are technical constraints involved with PCB designs that are daunting to the casual hobbyist. But it turns out that nowadays you can produce a professional PCB very inexpensively.

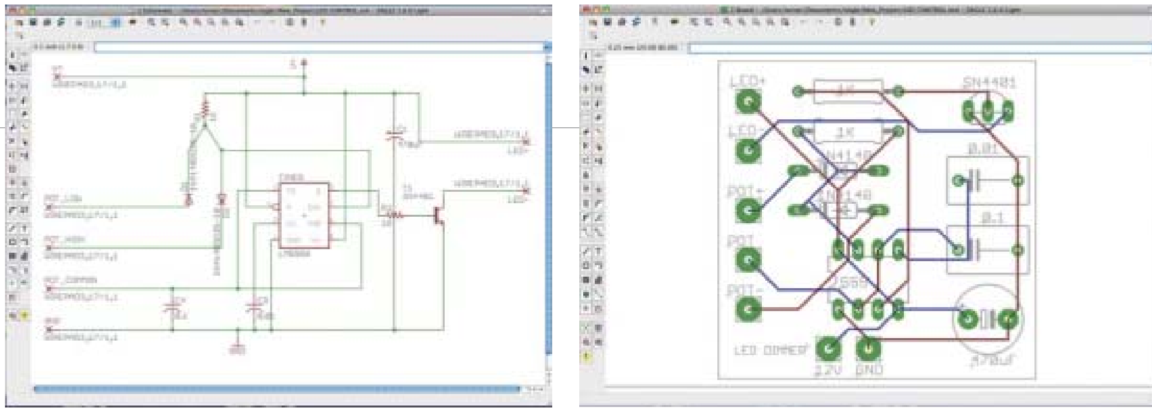
I only recently delved into the mysteries of PCB fabrication, for an upcoming *IEEE Spectrum* article on building a robotic digital microscope. Part of the project is a variable LED illumination system, and to dim LEDs you need to design a pulse-wide-modulation circuit. With a little research, I found a design based around a 555 timer chip, a power transistor, a couple of diodes, two resistors, and three capacitors. Not a huge number of components, but enough that I was dreading getting them all hooked up on a breadboard. Since I already had the design in hand, I was pretty confident it would work out of the box. That made it a perfect candidate for doing it as a PCB.

I had looked into custom PCBs a while back. I had even downloaded Eagle, a PCB design program from CadSoft Computer (http://www.cadsoftusa.com). I liked Eagle (and eventually returned to it for this project), but back then the cost of a single board—US $75 and up—stopped me. This time I discovered BatchPCB (http://batchpcb.com).

BatchPCB consolidates a bunch of individual projects onto a single large board and then cuts them apart when they come back from the factory. Small boards can be fabricated for under $20 this way. There's a three-week turnaround, but I wasn't in a hurry. I dove into designing my LED dimmer board.

A basic review of PCBs is in order here. A PCB consists of a thick, rigid insulating layer with conductive traces on the top and bottom. Because the middle

**ALL ABOARD:** The circuit board before [top] and after [bottom] it is populated with parts. PHOTOS: JAMES TURNER



**BOARD ROOM:** First lay out the components [left], then organize them and route the traces [right].
PHOTOS: JAMES TURNER

insulates, the traces on the top and bottom can run over each other. To get a signal from one side to the other, you drill a hole called a via, which is like a trace running through the board vertically. You also drill holes for ICs, resistors, diodes, and other discrete pieces. The traces lead to the holes, and the components have solder pads, allowing them to be soldered in place.

Some components may be connectors to bring signals to the board, and you can also leave larger holes with solder pad rings around them to solder external wires directly. You can even add layers with traces in between the top and the bottom, although this can get pricey. At BatchPCB, a two-layer board costs $2.50 per square inch (about $0.40 per square centimeter), while a four-layer board costs $8 for the same area (about $1.24/cm²).

The first step in creating a custom PCB is laying out the schematic view. Place your components (which usually come from a component library included with your design software) onto a canvas, and then connect the pins with lines representing electrical connections. You may find yourself faced with multiple choices for the same part number. That's because many components come in different packages, such as a DIP (dual in-line package) chip or a surface-mount chip. For hobby PCBs, you almost always want to go with the big, clunky DIPs and SIPs (system-in-packages), because they're easily found at hobby venues and are easier to solder than surface-mounted devices, which are meant for commercial applications. Although the various packaging options may look the same in the schematic view, they will appear very different when you go into the layout view to actually design the board.

In addition to your components and interconnections, you'll also have to place any needed power or ground signals. The Eagle library includes such components as VCC, VDD, and GND, for just this purpose. You also have to remember to place connectors on the board to bring in power and ground, as well as to connect the board to exterior devices such as LEDs or a potentiometer.

When you have everything where it needs to be, you can run an electrical rule check, or ERC, to make sure there are no glaring errors. Common problems include wires that look like they're connected but aren't (in Eagle, connected wires have little dots at the intersections) and power or ground connections you forgot to hook up. Remember that the ERC validates only the design's electrical properties, not that the board will actually do what you want!

Once you're happy with the schematic, you can switch over to the board layout view. When you first do this in Eagle, the components are scattered randomly, with the wires directly connecting between the pins. You should move around components in a way that makes sense (connectors at the edges, for example). You'll still be left with a rat's nest, however. In order to produce the board, you must assign signals to a layer, and different signals on the same layer can't touch.

With Eagle, you have to do this by hand unless you pay for the professional version, which has auto-layout capabilities that route your signals with the press of a button. Some PCB vendors offer their own design tools that can also do this for you.

With the signals laid out, you can finally run a design rule check, or DRC. This makes sure you won't have drill holes too close to signal lines or traces too close to each other or the end of the board. The rules are customizable, and BatchPCB offers a file that will set up Eagle with its preferred DRC values. If your design passes the DRC, you're ready to upload the design files.

You can (and should) also add silk-screen lettering on the top using a special layer. This printing indicates where components should go with outlines and part numbers, so you won't put that 100K resistor where the 1K one should go.

The lingua franca of PCB fabrication is the Gerber file, named for Gerber Systems, the original creators of the format. Each board will have multiple files. There's one for each layer and the locations of solder pads. A separate "drill file" defines where the holes will be drilled in the board.

When you upload these files to BatchPCB (following some fairly complete walkthroughs available on the site), BatchPCB runs its own DRC and also produces image files showing what the finished layers will look like. You can print these out and make sure your components will fit in the holes. Finally, just give BatchPCB your payment info and sit back for a few weeks.

When my boards arrived, I couldn't have been more pleased. They looked so professional, down to the silk-screened component symbols. Better still, they worked perfectly. I had ordered two boards, and paid $20 (of which $14 went toward setup and shipping). So I got my boards for effectively $10 apiece. At higher quantities the pricing works out even better.

If you've never designed a PCB, I highly encourage it. For $20, you're risking a bunch of time but hardly any money. And the pride you'll feel holding a commercial-quality board of your own making? Priceless.

—James Turner



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# geek life

## FILM PREVIEW: *HUBBLE 3D*

*Hubble 3D* is as close to a space walk as most of us will ever get

IT WAS like "brain surgery performed in boxing gloves," according to one of the seven astronauts who repaired delicate instruments on the orbiting Hubble Space Telescope last May. The story is recounted in a 3-D documentary that opened in IMAX movie theaters worldwide 19 March. A non-IMAX 3-D version will be released 23 April.

Narrated by Leonardo DiCaprio and directed by IMAX veteran Toni Myers, *Hubble 3D* is a loving celebration of the 20th anniversary of the world's most famous telescope. From a breathtaking close-up of the liftoff of the space shuttle *Atlantis*, which envelops the camera in smoke, to the successful instrument repair in bulky spacesuits, the 40-minute film chronicles the efforts involved in both the STS-125 mission and the filmmaking itself. It's a self-referential technique that IMAX documentaries have used before, for instance in describing an ill-fated ascent of Mount Everest.

The team used a combination of 149-kilogram IMAX 3-D cameras on the ground, a larger, 204-kg version aboard the shuttle—operated by two specially trained astronauts—and, affixed to astronaut helmets, 2-D digital cameras whose images were converted to 3-D in postproduction.

**SPACE GRACE:** Astronaut John Grunsfeld [top] passes a replacement cover to Drew Feustel during the repair work seen in the new IMAX 3-D film *Hubble 3D*. The crew members initially trained on a mock-up of the Hubble [bottom] at NASA's Neutral Buoyancy Lab at the Johnson Space Center, in Houston. PHOTOS: NASA

Each IMAX camera was customized to its particular shooting demands. The camera aboard the shuttle had to be encased in an airtight, pressurized enclosure.

After the shuttle landed, filmmakers had to wait a nail-biting month until NASA released the 30 minutes of space footage to them. "Until then, we didn't know how it would look," says Greg Foster, IMAX's chairman and president of filmed entertainment.

NASA had good reason to release the footage—the mission has already led to further astronomical achievements. "The most important discovery thus far from Hubble's repair came with the successful ultradeep infrared field that shows the farthest and earliest galaxies ever," says NASA spokesman J.D. Harrington, in one segment.

IMAX 3-D filming involves two cameras filming images concurrently on 70-mm film from right and left angles, which is akin to how our eyes perceive images. Audience members wear glasses that put the images together. An IMAX screen normally has a 1.43:1 width-to-height aspect ratio and is slightly concave and tilted down so that the images appear to envelop the viewer.

*Hubble 3D* is IMAX's eighth space-themed film and the first in partnership with NASA, which gave the filmmakers complete artistic control and didn't charge them payload costs. "NASA insiders always consider the Hubble the crown jewel of the space program," says Foster. "So they were thrilled when we asked to make a documentary."

—SUSAN KARLIN

technically speaking BY PAUL McFEDRIES

# Your Attention, Please!

You never expect 100 percent of people's attention. You learn to take 80 percent.—**rapper Ice Cube**

WHEN THE cardiologists Meyer Friedman and Ray Rosenman were researching personality types in the 1950s, they coined the term *hurry sickness* to describe the tendency to perform tasks quickly and to get flustered when encountering delays. By 1959 they had refined this to the now-classic term *type A personality*, a key element of which was a "harrying sense of time urgency."

Nowadays, this has a familiar ring to all of us. That's why some folks say we live in a **type A culture**, or an **accelerated culture**. This acceleration has also affected the adjectives we use to describe the world. The rat race is no longer merely fast paced; it's **amphetamine-paced** or even **meth-paced** (*meth* is short for the stimulant methamphetamine).

How do we keep up? We try to do several things at once. A *New York Times Magazine* profile of entrepreneur Mark Cuban reported that Cuban writes up to a thousand e-mails a day and didn't stop composing messages even while being interviewed. "Go ahead," he told journalist Randall Patterson, "I can multitask."

Many of us *think* we can multitask, and it really does look like we're doing several things at the same time when we listen to music and watch out for incoming e-mails and tweets while working on a multipage memo. We think we're paragons of **polyattentiveness**, the ability to watch or listen carefully to more than one thing at a time. But we're actually more like those old microprocessors that just switched from one process to another at lightning speed—we're getting good at rapidly shifting our attention from one task to another. Of course, this implies that we have some control over what we attend to. Increasingly, however, our lives are **interrupt driven**, characterized by constant or frequent interruptions, especially at work. (This term comes from computer science to describe a system that operates via interrupt requests, instructions that halt processing temporarily so that another operation can take place.)

Of course these attention shifts and interruptions come with their own problems, one of which is **continuous partial attention**, or **CPA**, a term coined by Microsoft researcher Linda Stone. This is a state in which most of your attention is on a primary task, but you're also monitoring several background tasks in case something more important or more interesting comes along. This leads to the **just-in-time lifestyle**, where you rush from one thing to another and expend only the minimum effort to complete a task; to **provisionalism**, where you never commit fully to what you're doing; and to what the philosopher and critic Raymond Tallis calls the **e-ttenuation** of work and relationships, as when, for example, you answer an e-mail or two while on the phone. There's a verb for that—**to background**, as in "Ever rung a colleague or client and found that the only response your questions are soliciting is the occasional 'Hmmm'? You've just been 'backgrounded'!" (*The Guardian*).

Similarly, rather than sit down to read a long magazine article or a good book, people **infosnack**, grabbing information in brief snippets. The goal seems to be to avoid the **microboredom** of having nothing to do over a very short period of time.

That our attention has become such a precious commodity is no surprise to those who study **attention economics**, an economic model that posits an **attention economy**, based on the static amount of attention consumers can devote to an ever-expanding pool of available information. In fact, the competition for our eyeballs and **earballs** (people listening to music, podcasts, radio, and so on), is so intense that some companies are now engaged in full-blown **attention warfare**.

Is there anything we can do to stave off these attentional assaults? One recent suggestion is the **digital cleanse**: the minimal use of digital technologies for a set period of time. Unthinkable, you say? Then how about practicing **disattention**? This is the deliberate refusal to pay attention to certain things. (For me it's celebrity gossip and Balloon Boy–like stunts.) While it may not help us win the **war of attention**, it just might help us reset our **attention rheostats** to a more comfortable level. ❑

BRIAN STAUFFER

## TOP 10 TECH CARS +++ 2010

*__FOR AT LEAST A DECADE,__ carmakers have been professing their deep and abiding interest in electric-drive vehicles whenever possible. But until recently, it wasn't always clear which of them were really sincere.*

*Today every last one of them seems sincere. As this year's "Top 10 Tech Cars" package shows, ever more varied hybrids are going into mass production, along with—you betcha—a few all-electric cars.*

*Some of the electric-drive machines aspire beyond mere greenness to heart-pounding performance, an aspiration that may seem strange to those taught to view electric cars as spacious, all-weather golf carts. But performance is indeed a logical goal, given the instant-on torque that electric motors provide.*

*While electrons may now be a recurrent theme of our annual Top 10 automotive reports, we do not slight the internal-combustion engine, which has lots of life—and technological enhancements—to come. And for those who don't spend a whole lot of time worrying about whether they're treading lightly enough on the planet's roads, we include two ultraperformance German sports cars that run purely on gasoline and adrenaline. One can easily be yours. If you're willing to trade in your house for it.*

*—Philip E. Ross & David Schneider*

MERCEDES-BENZ SLS AMG

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TOP 10 TECH CARS +++ 2010

## MERCEDES-BENZ SLS AMG

### Mercedes-Benz builds a modern supercar with classic styling

A tried-and-true trick in the auto industry is to resuscitate an old but elegant design while stuffing it with new technology. Daimler has pushed the concept to a whole new level with the Mercedes-Benz SLS AMG. It's a deliberate evocation of the most stunning design of all time, the 1954 300SL "Gullwing," whose doors opened like the wings of a bird (or an insect, if you want to get technical about it). Throw on another winglike structure that pops up at the back, pasting the wheels to the ground at speed and during braking and you're definitely in supercar territory. Indeed, reports say the SLS AMG will be priced at around €175 000 in Europe, where it'll be introduced this year, and somewhere north of US $200 000 in the United States, in 2011.

The car's list of tech features is long: a lightweight aluminum chassis and body; a 6.3-liter V-8 engine generating 420 kilowatts (563 horsepower); a seven-speed, dual-clutch transmission; a carbon-fiber driveshaft that rotates at engine speed to power the transmission directly; ceramic composite brakes; and a dry-sump oil system that uses special pumps to scavenge oil, which allows for a smaller oil pan and lets Mercedes give the car a superlow center of gravity. That feature, plus a front-to-rear weight distribution of 48:52, means the 1620-kilogram car handles like a fighter jet.

The ultimate tech feature, though, will come later, in an all-electric iteration pegged to debut sometime between 2011 and 2013. That model will have an electric motor for each wheel, generating a combined 392 kW (525 hp).

*—Philip E. Ross*

# Porsche Panamera

### Porsche's Panamera lacks only an ejection seat

AS MY PORSCHE PANAMERA TURBO hits its stride on the German autobahn, there's plenty to focus on, both inside and out. A V-8 engine is cranking 368 kilowatts (493 horsepower) to four churning wheels. The dual-clutch automated manual transmission fires off fast-twitch gear changes. A rear deck lid spoiler rises and widens at 90 kilometers per hour (56 miles per hour) to reduce aerodynamic drag, and then, as we cross the 200-km/h threshold, repositions like an airplane flap to boost downforce and stability.

But despite the mechanical marvels on display—and the voice in my head telling me to concentrate on the bends along this no-limit stretch of pavement—the most astonishing action is taking place in the backseat. There my driving partner remains blissfully asleep as I spur the Panamera to 300 km/h (186 mph to this Yank). That's more than enough to show a pesky BMW M3 and a Mercedes-Benz diesel wagon—which had been ankle-biting my Porsche for the past 10 km—where they rank in the autobahn's cruel pecking order.

Go ahead—call the Panamera ugly, ungainly, or just plain odd. You won't be the first to take issue with Porsche's fastback-roofed sedan, the first four-door car in the company's storied history. A traditional sports sedan, says chief designer Michael Mauer, would have been too easy. Instead, his team imagined a four-door sports car *mit* hatchback, penciling backseat dimensions to fit the lanky frame of then-CEO Wendelin Wiedeking, who is 188 centimeters tall (6 feet 2 inches).

"The Panamera does take some getting used to," Mauer says, even as he vigorously defends the beauty that derives from pure function.

Internal trickery runs the gamut: Adaptive Bi-Xenon headlights monitor vehicle speed and other parameters in order to swivel when going around curves; the lamps also automatically adjust their range and width to handle potentially dangerous situations, including two-lane back roads and foul-weather driving. A high-resolution screen holds a navigation system with 3-D renderings of buildings in major cities. The Burmester audiophile system has 16 speakers and more than 1000 watts.

The Panamera also raises the large-car performance bar to insane heights: Toggle up the electronic launch-control function and the US $133 000 Turbo catapults from 0 to 96 km/h (60 mph) in 3.8 seconds—as quick as the 911 Turbo, which weighs about 400 kilograms less—and covers a quarter mile in 11.7 seconds at 190 km/h (118 mph). That launch control requires getting the Sport Chrono option, which adds a fiddly lap timer and

**ENGINE: V-8, at 368 kW (493 hp)**
**BASE PRICE: US $90 000; Turbo: $133 000**

Road TESTED IEEE Spectrum

the all-important Sport Plus mode to the car's myriad computerized performance systems.

Even the 294-kW (394-hp) Panamera S and all-wheel-drive 4S models squirt to 96 km/h in less than 5 seconds. That robust power stems from a 4.8-liter, direct-injection V-8 with dual turbochargers and extensive weight-saving materials, including magnesium valve covers and aluminum camshaft adjusters. Crankshaft and connecting rods trim a remarkable 2.3 kg (5 pounds) from those on the Cayenne S's same-size V-8, reducing critical reciprocating mass for swifter engine response. The Panamera S retails for about $90 000 and the all-wheel-drive 4S adds another $4000 to that sticker price.

A less costly, 220-kW (roughly 300-hp) V-6 Panamera will go on sale this year. A Panamera hybrid will follow in 2011, mating a V-6 with an electric motor that together should approach 298 kW (400 hp).

In the V-8 models, the low-mounted engine drops the car's center of gravity to enhance handling, an arrangement made possible by a lateral driveshaft that runs directly through the engine's crankcase, rather than being positioned below it. Dry-sump lubrication, common in race cars, ensures that the Panamera gets a steady serving of oil, even when the car is undergoing extreme *g* forces that can starve an ordinary engine of lubrication. European models get a fuel-saving engine stop-start function, similar to that of hybrids, yet Porsche nixed the system for American owners. There, the Porsche still dodges a gas-guzzler tax, with the Turbo estimated at 15 miles per gallon in the city and 23 mpg on the highway (15.7 and 10.2 L/100 km).

The Panamera adopts the new Porsche-Doppelkupplung transmission, or PDK, a slick dual-clutch unit that's far faster to shift than it is to pronounce. A driver can cruise in comfy automatic mode or shift manually over a range of selectable performance programs, using paddle shifters or the console lever. One clutch handles gears 1, 3, 5, and 7, the other gears 2, 4, 6, and reverse, with one clutch releasing a gear as the other simultaneously grabs the next successive speed, up or down. Other carmakers have implemented such a scheme, but Porsche's refinements permit near-instantaneous gear shifts, along with a transmission that can downshift multiple gears (for example, from fifth to second) the instant you floor the gas pedal.

An adaptive air suspension features what Porsche calls a world first: air springs that adjust by adding or subtracting air volume. The feature relies on two things: a road-sensing calculator, called the Porsche Active Suspension Management (PASM) system, and performance maps selected by the driver. In Comfort mode, each spring holds 2.2 L of air for a gentler ride. In Sport mode, valves close and reduce the volume to 1.1 L, firming the suspension

*Continued on page 58*

# FORD TAURUS SHO

## Ford gets its radar from a fighter plane

The top of this year's Ford Taurus range is the powerful and jazzy Taurus SHO (for "super high output"), a sport sedan. Chief among the technical bragging points is an optional safety feature known as electronically scanning radar. This guardian angel scans the highway far enough ahead to save you from rear-ending a fog-shrouded forerunner while going wide enough to catch any would-be lane changer that may be lurking in your blind spot. Because its microwaves penetrate fog, it beats the older, laser-based systems.

Ford crows that the device, supplied by Delphi, is derived from a radar used in the F-22 Raptor fighter jet. Of course this sort of thing can also be done by mechanical scanning—like a dish antenna sweeping the sky—but by steering the beam electronically you get not only better performance but also a far more compact package that's a mere 5 by 8 by 18 centimeters long. That makes it easy to fit the radar's forward-looking part into the car's sleek front end. Other car companies offer such radars, but Ford gets our plaudit because it charges just US $1195, far less than any competitor.

In practice, the radar functions as part of a larger system of adaptive cruise control—a baby step along the road to automated driving. When the radar senses the hint of a threat of an impending collision, it alerts the driver and precharges the brakes, so they'll react that much faster to the driver's foot. *—Philip E. Ross*

**ENGINE: 3.5-L turbo V-6, with 272 kW (365 hp) and 474 Nm (350 ft-lb) of torque**
**BASE PRICE: US $37 700; add-on adaptive cruise control: $1195**

ALL PHOTOS PROVIDED BY MANUFACTURERS

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# Audi e-Tron

## Audi's electric concept car is an all-wheel-drive shape-shifter

Electric Concept CAR

THE AUDI E-TRON ALL-ELECTRIC sports car—a direct challenge to the much ballyhooed Tesla Roadster—is chock-full of gadgetry, including a heat pump (rather than a heater), an ultralight aluminum and composite body, and a shape-shifting exterior that deploys movable grilles and the like to reduce drag and to channel cooling air past the battery.

And, unlike most concept cars, the e-Tron actually goes. At least, that's the word from automotive writers who've driven one. The machine packs plenty of motive power in the form of four motors, one for each wheel. Some automotive engineers would cringe at having to suspend and shock absorb all that unsprung, rotating mass, but this arrangement allows for a precise, fourfold, moment-by-moment split of torque among the four wheels.

And quite a bit of torque it is. Gearing in the front and back lets the motors, 230 kilowatts (312 horsepower) in all, churn out the equivalent of 2650 newton meters (3320 foot-pounds), more than the frame could bear if automatic controls didn't set a limit way, way below that number. The result is still enough to kick you from 0 to 100 kilometers per hour (62 miles per hour) in under 6 seconds. Audi estimates it can go 240 km (150 miles) on a charge of its lithium-ion battery pack, the usable portion of which is rated at 43 kilowatt-hours.

Clearly, Audi wouldn't have made this concept car so immediately drivable if it weren't planning on turning it into a production car. So is electricity the future of supercars? Perhaps. Everyone presumes that an electric car is good mainly for the environment, or for reducing an auto company's average fleet fuel-economy rating. In fact, an electric car—with its stupendous torque—has the potential to beat many a gas burner in a sprint. It's a natural technology for a supercar. *—Philip E. Ross*

# VW UP LITE

## VW's concept car marries electricity to diesel

Hybrid Concept CAR

How do you build a practical car that's highly fuel efficient? Easy: Make it small and light, give it a diesel engine, and make that engine part of a hybrid power train. Strangely, no such creature has yet hit the road. Several automakers are, however, fixing to correct that oversight. In particular, Volkswagen is testing the waters with its Up Lite concept car, which shares many components with VW's "New Small Family" of cars, which the company will begin offering buyers by 2012.

The Up Lite is, as you might expect, quite light: 695 kilograms (1532 pounds). VW shaved its weight by keeping it small (the car is just 3.84 meters long) and making many of its parts out of aluminum and carbon composites. Some axle components are even made from magnesium. Small and light? Check.

The Up Lite's engine is a two-cylinder, turbocharged, direct-injection diesel of just 0.8 liter displacement—a truncated version of the larger turbo direct-injection diesels Volkswagen is well known for. Diesel engine? Check.

The Up Lite gains 38 kilowatts (51 horsepower) from its diesel engine and another 10 kW (13 hp) from an integrated electric motor, which, in addition to powering the vehicle and providing for regenerative charging of the car's lithium-ion battery, replaces the usual starter and alternator. Hybrid power train? Check.

ENGINE: **38-kW (51-hp) diesel engine combined with 10-kW (13-hp) electric motor**

This engine-motor combination is connected to the wheels through a seven-speed "direct shift gearbox"—think of it as an automated manual transmission—which is said to accelerate the car from 0 to 100 kilometers per hour (62 miles per hour) in 12.5 seconds, to provide a top speed of 160 km/h (about 100 mph), and achieve 3.4 liters per 100 kilometers (70 miles per gallon) on the highway.

The Up Lite sports plenty of other eco bells and whistles, including rear-facing video cameras instead of drag-inducing side mirrors, a front grille that automatically adjusts to engine-cooling needs, and power-train settings that can be altered using a touch screen mounted near the center console.

*—David Schneider*

*AUDI E-TRON*

POWER PLANT: **Four electric motors, totaling 230 kW (312 hp)**

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TOP 10 TECH CARS +++ 2010

# Fiat Nuova 500

## Fiat's retro car runs on gas—and soon on natural gas

IN JULY 2007, exactly 50 years after the original Fiat 500 rolled off the assembly line, Fiat unveiled its Nuova 500. The company was following what BMW and Volkswagen had already done for the Mini and Beetle—creating a modern vehicle styled after one of the iconic cars of postwar Europe. But Fiat is now taking a big technological step forward by putting an advanced new engine into its cute little retro car.

Later this year, Fiat will offer the Nuova 500 with its new Small Gasoline Engine, or SGE. Like the little putter in the original Fiat 500, the SGE has only two cylinders, giving a displacement of just 900 cubic centimeters, about the size of what you might find powering a Ducati.

But this is no ordinary motorcycle engine. It's got a start-stop system to shut down the engine when the car is stationary, and some versions will include turbochargers, providing as much as 78 kilowatts (105 horsepower). And the engine will include Fiat's new MultiAir variable valve timing, an electromechanical system that independently actuates each cylinder's two intake valves, to let the engine deliver more power at high revs without sacrificing torque or drivability at low engine speeds.

**ENGINE:** Two-cylinder, 900-cc gasoline (or natural gas)
**BASE PRICE:** Likely around US $15 000

Variable valve timing has been around for years. What distinguishes the MultiAir system is that it gives fine control of the intake valves using a solenoid and hydraulic pressure generated by the camshaft. It has two other slick features: It allows exhaust gases to be recirculated merely by opening the input valves during the exhaust stroke, and it eliminates the need for a throttle mechanism to reduce airflow into the cylinders.

In July 2009, Fiat said it would introduce the car to the U.S. market by early 2011. Adding to ecodrivers' excitement, Fiat plans to follow up with a hybrid SGE along with a version that can burn compressed natural gas. So Fiat's Nuova 500 combined this year with the company's new SGE power plants will surely help to illustrate how, with the right technology, downsizing can be downright exhilarating. —*David Schneider*

THE BEAST WITHIN: **The V-8 engine, with twin turbochargers, packs plenty of power in a petite package.**

# BMW X6 M

## BMW stuffs a big engine into a small package

As engineering achievements go, the world's fastest SUV might seem on a par with a hydroelectric stapler or a self-buttoning cardigan: interesting, but pointless. Ignoring the howls of automotive purists and Sierra Club donors, BMW has bestowed on us the X6 M. Like BMW's M3 and M5 sedans, this offshoot of the standard X6 crossover wears the "M" badge that denotes the company's explosive high-performance division. And while the X6 M looks more like Batman's assault vehicle than a traditional sports sedan, there's no disputing the engineering heroics that let this 2380-kilogram (5247-pound), 408-kilowatt (547-horsepower) beast thumb its Bavarian nose at the laws of physics.

The BMW imperils highway laws as well, which made track testing both welcome and enlightening. Over two separate weeks with the X6 M, I was impressed with the BMW's Jekyll-and-Hyde personality: one part fleet, serene cruiser with room for four adults and decent cargo space, despite its slope-roofed styling; one part roadway killer that needs the curves at Pennsylvania's Pocono Raceway or New York's Monticello Motor Club to achieve complete and blissful self-actualization.

Detailing the BMW's myriad technologies would require a dissertation, but let's start with the Cliffs Notes: Using the 300-kW (402-hp), all-wheel-drive X6 as a starting point, the mad scientists at the M division drew up a new, direct-injection V-8 with pricey twin-scroll turbochargers and a patented, world's-first "crossover" exhaust manifold. A raft of computerized handling aids—including a sophisticated active rear differential—work magic in extreme cornering maneuvers. An automated launch control unit catapults the BMW to 100 kilometers per hour (62 miles per hour) in 4.7 seconds, keeping up with a standard Corvette that weighs a ton less.

Twenty-inch wheels with ultrahigh-performance tires are grappled by shockingly large brake rotors—the ones up front measure 39.6 centimeters (15.6 inches)—whose two-piece composite design trims about a kilogram of critical unsprung weight from each wheel, boosting ride and handling. The body gets its own M additions to boost style, aerodynamics, and cooling, including front air inlets whose gaping nostrils seem straight off a Lamborghini.

The cabin of this "sports activity coupe," as BMW calls it, is equally chockablock with features. Driver-selectable performance settings adjust the engine, throttle, six-speed paddle-shifted automatic gearbox, and electronic suspension—the latter reading information from the road surface to adjust shocks at up to 400 times per second (really, couldn't 350 have sufficed?). Amenities include a head-up display and a 16-speaker audio system.

The engine is a 7000-revolution-per-minute masterwork. Dual turbochargers and their catalytic converters are actually nestled between the V-shaped cylinder banks; BMW's ingeniously compact layout has been used on no other production V-8 in history. The challenging design required exhaust valves mounted inboard and intake valves outboard, the opposite of the tens of millions of standard V-8 engines produced over the last century.

That reverse layout isn't just for show: Power-boosting exhaust gases travel a much shorter route to the turbochargers and catalytic converters, meaning less wasted energy and superior emissions performance. The crossover manifold is another BMW first: Spent gases are routed through four pairs of cylinders on opposite banks, with each pair's ignition separated by 360 degrees of crankshaft revolution. Each pair then feeds into an individual exhaust runner and turbocharger scroll; essentially, the engine works like a four-turbo design. Four exhaust runners of identical length mean that the turbines receive perfectly consistent pulses of exhaust gas, boosting gas velocity and virtually eliminating dreaded "turbo lag," the brief lapse between stomping the gas pedal and feeling the love when the turbos kick in.

JEKYLL—OR HYDE? **Part family car, part roadway killer, the X6 M occasionally needs to stretch its limbs on a racetrack's curves.**

For drivers, the result is a delightfully broad and ferocious power curve, with all 680 newton meters (501 foot-pounds) of torque fully on tap between 1500 and 5650 rpm. The engine's unusual architecture also produces a one-of-a-kind sound, a mellow, baritone *blat* as opposed to the chesty roar of a typical V-8.

Next, the BMW's xDrive all-wheel-drive system adds a feature called Dynamic Performance Control—the active rear differential that helps maintain stability and even nudge the vehicle around turns. Dubbed Vector Drive by its maker, Germany's ZF Friedrichshafen, this complex arrangement of multidisc clutches and planetary gear sets act on speed and *g*-force information gathered from sensors at all four wheels.

Combining that data with complex algorithms from the electronic stability control system, the unit can vector full engine torque from one rear wheel to the other—a differential of up to 1800 Nm (1328 ft-lb)—in as little as 100 milliseconds. During a right-hand corner, for example, the left rear wheel speeds up, and the right rear wheel rapidly slows down, creating a pivoting force called a yaw torque. Those lightning-quick adjustments also keep the vehicle on the driver's intended path, neutralizing both understeer—the tendency of a vehicle's front wheels to skid—and oversteer, when a car fishtails from the rear.

The system may sound arcane, but the results are noticeable on road and track alike. On a damp track at Monticello, I could feel the active differential help pivot the BMW's rear through fast corners, like a helpful football coach twisting a lineman's hips to improve his footwork.

The unfairness of the situation, in both accelerative force and tech-enhanced traction, wasn't lost on a colleague driving a 217-kW (291-hp) Mitsubishi Evolution all-wheel-drive sedan on Monticello's snaking course. That colleague saw the usually

*Continued on page 58*

10 TOP 10 TECH CARS

BUG, ALIGHTING: **Those swoopy looks do more than dazzle; they resist the air less than the skin of any other car.**
PHOTO: GREGG SEGAL

Road TESTED ieee spectrum

# Aptera 2e

## Aptera unveils its all-electric, three-wheeled two-seater

THE APTERA 2E IS A CESSNA CABIN without wings—a teardrop with a sharply tapered tail slung between two outrigger front wheels. It's a three-wheeled, two-seater, all-electric bug that slips through the air more easily than any other production car in the world.

So perhaps the most unusual thing of all about the Aptera is how normal it feels when you're behind the wheel. The prototype I drove last year was far from the production model that's scheduled to be unveiled in April. Still, it gave me a good sense of how the final car will handle on the road.

I took it through the curvy, rolling hills of the industrial park that houses the Aptera Motors headquarters, in Vista, Calif. The visibility through the car's panoramic windshield was great, enhanced by a driver's seat that sits higher than the car's shape would suggest. Rearward visibility is another story. Reversing an Aptera is something between an adventure and a blind stab in the dark. With tiny side mirrors, an almost horizontal rear hatch, and high taillights, the view out back is likely to remain a challenge no matter how much glass is used. Aptera says a rear-vision video system will be offered as an option. My advice is, take it.

The car holds the road as well as any four-wheeler, with remarkably level cornering and less body roll than most mass-market cars. That may be due to the extra-wide distance between the prototype's front tires, which will be narrowed to make the production car easier to park. The ride, however, was quite firm, with distinct clunking as the car went over ridges and heaves. Aptera electrical engineering project manager Brian Gallagher said the production car's suspension will be considerably more refined. [See Gallagher's profile in "Dream Jobs 2010," *IEEE Spectrum*, February.]

The car's 75-kilowatt electric motor is powered by a 20-kilowatt-hour lithium-ion battery pack. Performance feels brisk, especially in accelerating from a standstill to 50 kilometers per

# NISSAN LEAF

## The experience electrifies—until the battery dies

Road TESTED ieee spectrum

First a left turn, then a speedy stretch, and then a gentle, swishing zigzag through a parade of orange cones. The drive is nothing to report on, and *that's* the story, because I'm running not on gas but on electrons.

I'm in an old train-station parking lot on a wintry morning in Vancouver, and I'm behind the wheel of one of this year's most eagerly anticipated cars. Well, sort of. The car is actually what engineers call a test mule: It's got the guts of a Leaf, Nissan's first pure-electric vehicle, but the body of a Versa sedan, Nissan's plain-Jane budgetmobile. Due out in parts of Japan, the United States, and Europe late this year, the Leaf will be the world's first affordable, mass-market, all-electric car, Nissan says. And it'll also be one of the first electric vehicles from a mainstream maker with state-of-the-art lithium-ion batteries. Nissan says it will have a range of 160 kilometers (100 miles) on a charge and will deliver a respectable 280 newton meters (207 foot-pounds) of torque.

LOOK, BUT DON'T TOUCH: **The final version of the Leaf [above] looks sleeker than the test mule we drove.**

Under the hood, the Leaf's 80-kilowatt synchronous AC motor drives the wheels directly, without a gearbox, delivering maximum torque starting at zero revolutions per minute. Though Nissan declines to specify the acceleration, it claims the Leaf tops out at 145 kilometers per hour (90 miles per hour).

In Vancouver, Nissan also provided a look-but-don't-touch model of the real Leaf. It looks a lot like a Toyota Prius, with a sloped front and a boxier back end. The interior has a futuristic feel, with a glowing blue console and, in place of a shifter, a mushroom-shaped controller (video gamers rejoice!). As a bonus, the car will be able to tell you where nearby charging stations are. It'll even tell your smartphone when it's finished juicing up.

But it's the Leaf's zero-emissions potential that has some of the attendees in Vancouver salivating. "This will take my carbon footprint almost to zero," one crows. Another declares, "If you have two cars, this should be one of them."

The Leaf is a big gamble for Nissan. Unlike other major automakers, Nissan has bypassed hybrids in favor of pure-electric cars. President and CEO Carlos Ghosn's



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hour (31 miles per hour). I was even able to spin the inside front wheel accelerating out of a curve. With electric motors developing peak torque starting at zero revolutions per minute, all-electric cars like the Aptera and the 2011 Chevrolet Volt promise to bring new smoothness and performance to everyday stop-light sprints.

Aptera projects a maximum speed higher than any U.S. speed limit, and high-speed performance will clearly be helped by the 2e's jaw-droppingly low drag coefficient of 0.15. If the company pulls it off, that will be the lowest ever achieved on a production vehicle. By comparison, GM's legendary EV1 electric vehicle, also a two-seater, had a drag coefficient of 0.19, and the two-seat Honda Insight is rated at 0.25.

The shape of the 2e prototype will carry over into the final production version, but the door windows will be deeper and the triangular rear windows will be larger, Gallagher says, letting more light into the cabin. The fairing that covers the rear wheel (or wheels, because one prototype I saw had a pair of closely spaced wheels) will be longer, as will the rear window.

Entering an Aptera requires a bit of practice, because the car's doors pivot up and out, gull-wing style, and the openings are smaller than a standard vehicle's. Closing the door requires a reach for shorter drivers. Once inside, I found interior space to be perfectly adequate for two people. The tail contains a lot of empty space behind the seats, though the long, tapering shape of the space makes it unclear how Aptera will design this storage area to make it useful. Aptera says the production 2e will be about 10 percent larger than the one I drove and will be fully rechargeable in less than 10 hours on standard North American 110-volt current.

The development prototype had its share of creaks and groans, along with a largely unfinished interior. Its hand-laid composite body shell was smoothly finished, although lights, wipers, and mirrors will all be modified before production.

Aptera will test the 2e to ensure it meets all U.S. federal motor vehicle safety standards, including front, side, and rear impact tests. Indeed, its egg-shaped body is probably closer to the perfect shape for a strong monocoque than any other car on the road. But features requested by consumers have required some changes that were not reflected in the prototype I drove, including the addition of roll-down door windows to make it possible for drivers of Apteras to use the drive-through windows at fast-food joints and banks. That meant reengineering its curved doors to accommodate both strengthening beams and movable windows.

The Aptera has two kinds of braking: Friction brakes on all three wheels serve in short-distance stops and emergencies, and a motor, when reversed, serves as a regenerative brake. That is, the resistance the motor offers to forward motion gets turned into electricity that recharges the batteries.

Aptera says it will provide owners with the most complete and flexible platform available for "infotainment" and the display of operational data, letting drivers analyze their energy usage in gory detail. The company *Continued on page 58*

# HONDA CR-Z

## Honda tunes its hybrid for power

**ENGINE:** 1.5-L, 81-kW (109-hp) gasoline engine with 10-kW (13-hp) integrated motor assist
**BASE PRICE:** Expected to be about US $20 000

To wealthy environmentalists, hybrid cars have always been more than transportation: They are a roving statement of their convictions. Sadly for such drivers, though, the only mainstream hybrids available in North America are dowdy family cars and boxy SUVs. Anyone wanting a hybrid with more pizzazz has been out of luck. That's about to change.

For the 2011 model year, Honda will be offering a hybrid sports car, the CR-Z. The car is modeled in both name and styling after Honda's diminutive sports coupe of two decades ago, the CR-X, which was celebrated for phenomenal fuel economy.

Naysayers disparage the Environmental Protection Agency's disappointing mileage projections for the CR-Z—31 city and 37 highway miles per gallon (7.6 and 6.4 liters per 100 kilometers, respectively) for the standard-transmission version. But they should note that drivers of Honda's new Insight hybrid can easily beat the EPA's fuel economy rating around town by about a factor of two. So it remains to be seen what kind of mileage careful drivers will be able to eke out with a CR-Z in the real world.

Opting for the continuously variable transmission would help in that regard, because it is expected to provide an EPA-estimated 36 city and 38 highway mpg (6.5 and 6.2 L/100 km). But, come on now, what sports-car enthusiast is going to buy an automatic?

With the CR-Z, the driver selects one of three modes: sport, normal, or economy. The choice affects the setting of the car's electric power steering, engine responsiveness, electric power assist, and air-conditioning compressor, managing them so as to save gas to a greater or lesser degree. So the economy mode may provide very respectable fuel efficiency—and in a car that should have no problem impressing a date. *—David Schneider*

plan is to move fast to capture a sizable share of the market for pure EVs, which Nissan expects to account for 10 percent of global car sales by 2020.

Nissan will say only that the Leaf will cost about as much as a conventional gasoline-powered five-person sedan, such as its Sentra or Altima. That puts the car somewhere between US $15 000 and $25 000, although the company hasn't made clear whether that price range will include the full cost of the battery. Nissan also says there won't be a "green premium": Average drivers will spend much less on electricity than they would spend on gasoline in a comparable, conventional car.

And it's smooth. In a Prius, there's a slight thump when the engine kicks in. Not so in the Leaf, because there's no engine. There's just a satisfying punch when you stomp on the accelerator.

The car's biggest novelty—the battery—lies beneath the back seat. Conventional lithium-ion packs consist of cylindrical cells encased side by side, creating air pockets that trap heat and require auxiliary cooling, which saps efficiency.

Nissan's new batteries consist instead of sheets of lithium manganese and graphite, stacked in waferlike cells, each about the size of a manila envelope. Four of these cells get packed into a box the size of a textbook. Nissan managed to fit 48 such boxes beneath the seat and under the floor. Simple airflow is enough to cool them. The battery can deliver 90 kW of power and has an energy capacity of 24 kWh, about twice that of Nissan's previous lithium-ion batteries of the same size. And Nissan's already working on a version with a lithium nickel manganese cobalt oxide cathode, which might double again the battery's capacity.

A big pothole, though, may lie ahead for Nissan. It doesn't matter how good the batteries are if you can't easily recharge them. As with other electric cars, the biggest challenge for the Leaf is the charging infrastructure. "If it's not easy for customers, it's not going to work," acknowledges Nissan Canada's marketing director, Mark McDade.

So the company is working hard to make it easy. Nissan recently announced that if you buy a Leaf, it will have a contractor install a charging station in your garage before the car arrives. With a 220-volt charger, you can replenish a fully depleted battery in 8 hours. Nissan is also prodding governments and electric utilities to deploy public charging stations, which could charge the battery up to 80 percent in just under 30 minutes to support long-distance driving.

Here in Vancouver, with snow threatening to fall any minute, I return to the test track one last time. I want to check a feature I'd forgotten to pay attention to: noise—or the lack thereof. All I can hear is a cool electric whine of the motor as I accelerate. When I stop, it's totally quiet. So one last bit of advice for future Leaf owners: After parking the car, double-check that you've hit the "off" button before walking away. You don't want those precious electrons to trickle out.
*— Anne-Marie Corley*



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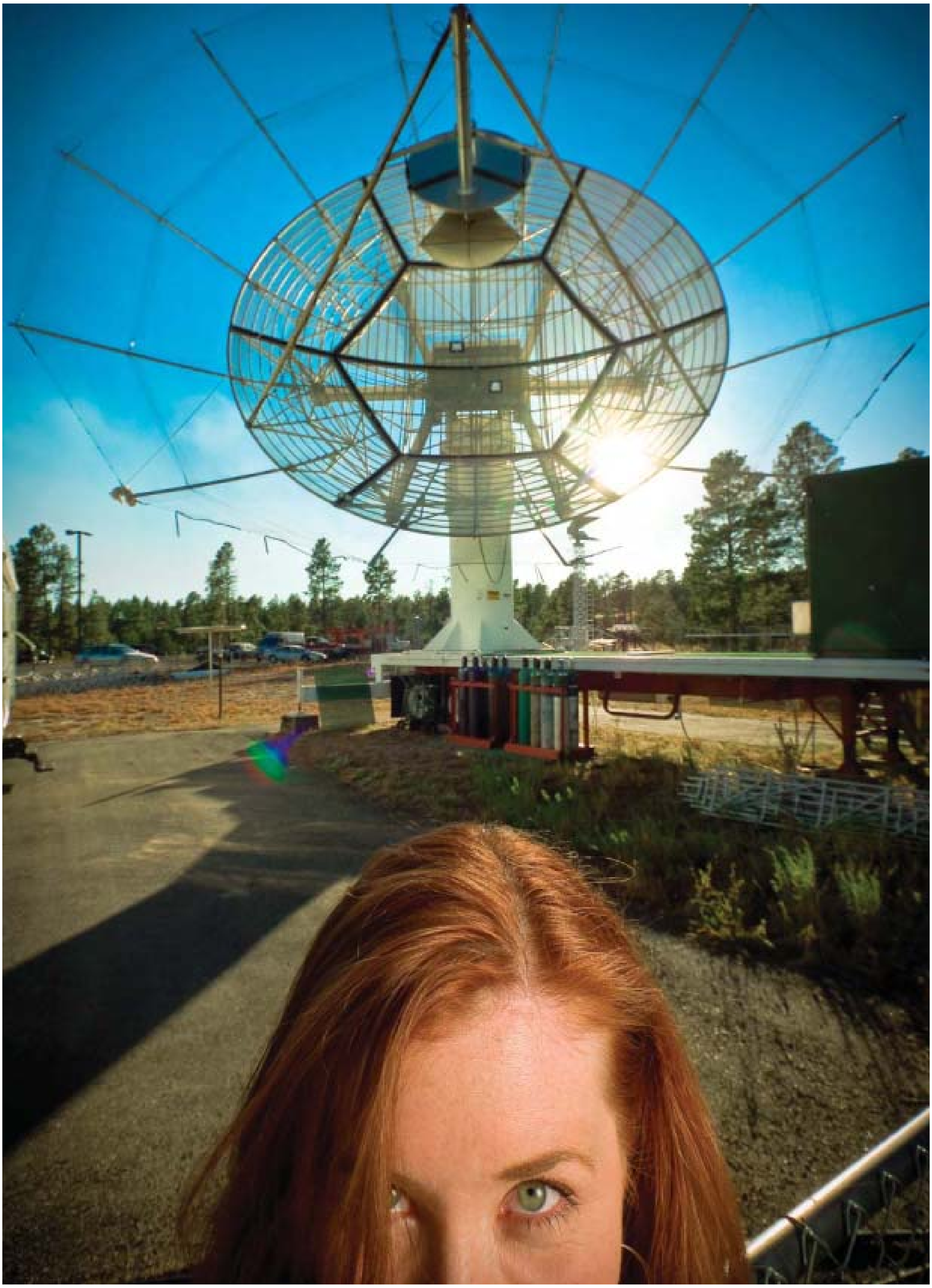

**STAR TRACK:** The author with the Los Alamos Portable Pulser, which beams VHF signals that satellites can detect. *PHOTO: CHIP SIMONS*



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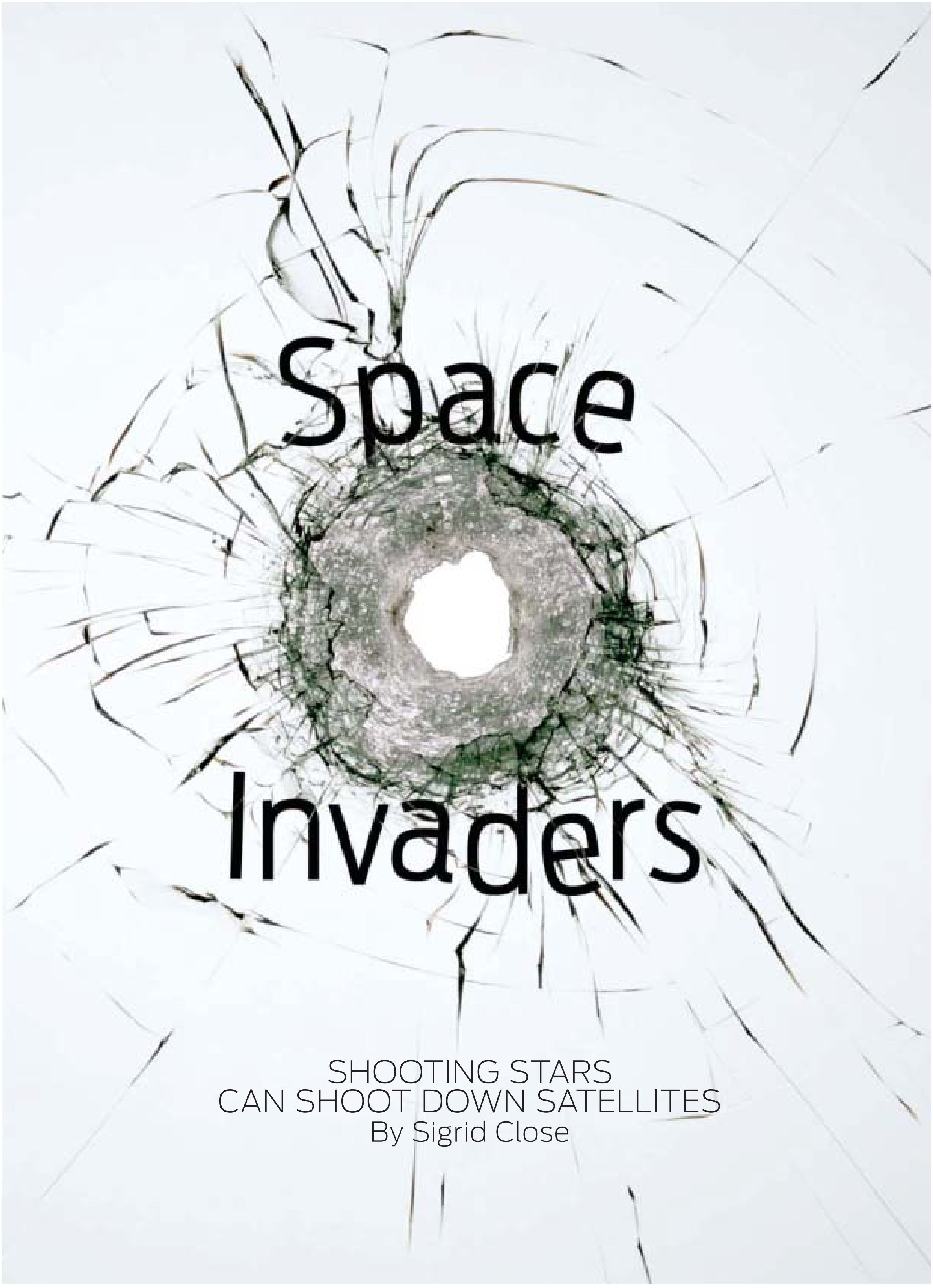

# Space Invaders

SHOOTING STARS CAN SHOOT DOWN SATELLITES

By Sigrid Close



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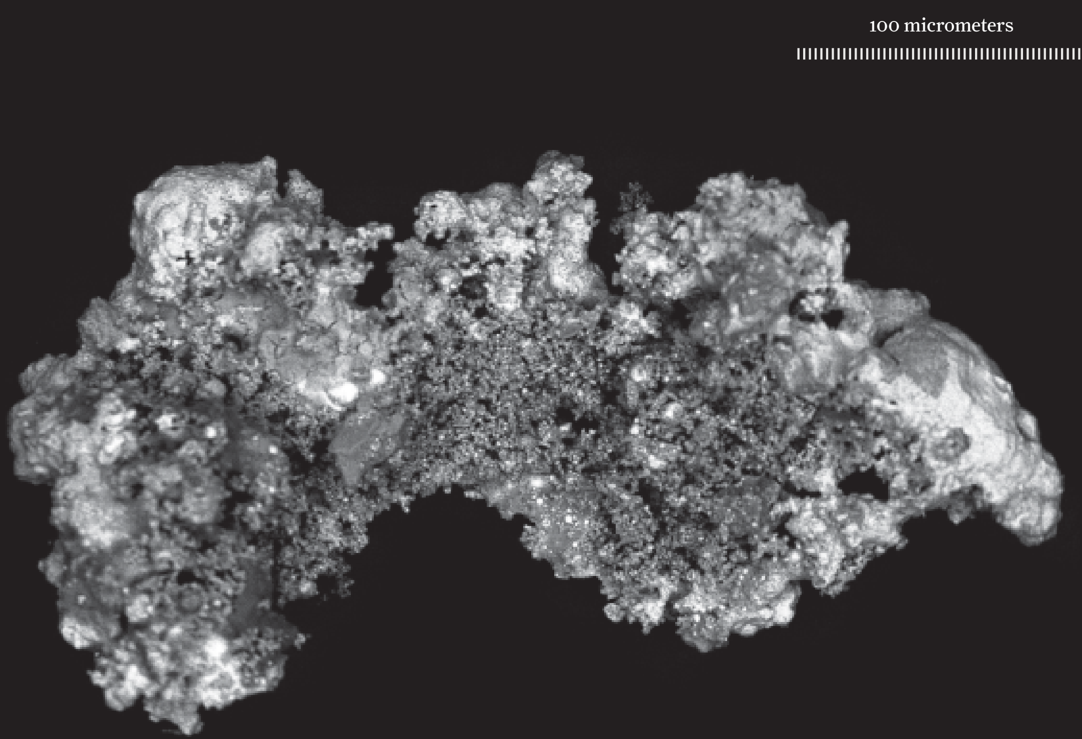



In August 1993, the European Space Agency's Olympus 1 experimental satellite was in trouble. The annual Perseid meteor shower, especially fierce that year, was just getting started. Usually, given sufficient warning of intense meteor activity, satellites can engage their defenses: They might, for example, protect themselves against incoming projectiles by orienting their solar panels against attacks, like shields. But Olympus 1 was at a disadvantage. A previous mishap had disabled the satellite's ability to shift its solar arrays, leaving it defenseless. In short order, an incoming Perseid particle knocked out Olympus's gyroscope stability, which sent the satellite spinning wildly. Attempts to regain control used up most of the craft's fuel, leaving the US $850 million satellite with barely enough to propel itself into a graveyard orbit, where it could neither hit other satellites nor do much of anything useful. Olympus 1 will likely remain there forever, cold and dead before its time.

In 2009, Landsat 5, a satellite jointly operated by NASA and the U.S. Geological Service, also began to spin out of control, again during an August peak of the Perseid meteor shower. Far below, satellite trackers scrambled to find out what had happened.

**SHOOTING STAR:** This meteorite was found in the snows of Antarctica. Millions like it pelt Earth's atmosphere every day; few survive the trip. Meteoroids burn up before they hit the ground.

*ABOVE: SNSM-ORSAV-CNRS/IPEV; PREVIOUS PAGE: DON FARRALL/GETTY IMAGES*

Had the satellite been hit by a stray rock from space? Was the culprit a solar storm or an impact with one of the thousands of pieces of orbiting debris shed from other spacecraft or booster rockets? Or was the cause more alarming: an attack from a hostile nation?

Satellite failures such as these have cost the governments of the world billions of dollars. So it might appear strange that there are still huge gaps in our understanding of what can go wrong in space. Space agencies all over the world often struggle to figure out what has happened when some piece of hardware in orbit goes haywire. How can they differentiate between a malfunction caused by a tiny rock hurtling in from interplanetary space and an errant screw left in orbit decades ago? And more important: How can engineers properly protect spacecraft from such projectiles—whatever their provenance?

We live in a time when sending people to Mars is beginning to look like a real possibility, China has announced its plans to set up a moon base by 2030, and soldiers in the field depend on GPS satellites. And that's not to mention regular citizens, who are finding it hard to live without the things satellites provide: long-distance communications, much of their entertainment, and help navigating around town. Therefore, many of us in the space sciences community are renewing our efforts to understand the myriad natural and artificial dangers that spacecraft constantly face.

AFTER 53 YEARS of sending equipment into space, planet Earth has accumulated a thick mantle of space debris. We are able to track about 20 000 objects—although the estimates that account for objects under 10 centimeters in diameter put the total number closer to 600 000. When a satellite hits an object in this belt, the collision may cause the satellite to splinter into many fragments, which then add to the accumulating debris. And because the satellite has been destroyed or crippled, it becomes necessary to send a replacement, increasing the potential for more debris later on.

Satellite designers can fashion shields that guard reasonably well against impacts with small pieces of space debris. And satellite operators can usually track and avoid the larger chunks, although sometimes that process doesn't go so smoothly. Within the past year, both the space shuttle *Discovery* and the International Space Station had to take rapid evasive action to dodge one especially treacherous object. And in February 2009, Russia's defunct Cosmos 2251 satellite collided with an Iridium Communications satellite, unlikely to be the last accident of its kind. Such incidents have prompted spaceflight operators to coin the term "space situational awareness." It's an acknowledgment that you need to see and understand what's going on in space. The growing focus on space situational awareness comes partly from the sheer number of satellites now in orbit and partly from the vulnerabilities inherent in the crowded, busy lanes of near-Earth space.

Adding to these concerns, a 2007 Chinese antisatellite test showed that even this newcomer to the space race is capable of destroying a target in low orbit using a ground-based missile. Another worry is the growing popularity of small satellites, often dubbed microsats or nanosats—names that don't reflect their real size—which typically measure a few centimeters. Because these objects are hard to track and maintain in their proper orbits, they pose headaches for the people whose job it is to catalog everything circling Earth.

In the United States, the Air Force and NASA bankroll most of the fundamental research on reducing the threat of collision in space. Both organizations have obvious interests in being able to travel in space or to place useful objects into orbit.

I HAVE WORKED with Bill Cooke at NASA's Marshall Space Flight Center and with researchers at the Air Force's Office of Scientific Research throughout my career, first while I conducted studies at MIT Lincoln Laboratory and later at Los Alamos National Laboratory, where my team searched for ground-based electromagnetic pulses using LANL's radio frequency sensors, and now as an assistant professor at Stanford University. All the while, my job has been to learn about the dangers to spacecraft. I try to understand the many complications that can make a satellite mission go awry, including run-ins with orbital debris, lightning, and solar flares. My primary focus, however, is meteoroids, which are solid extraterrestrial bodies smaller than a boulder but larger than a dust grain.

Satellite engineers have done much to mitigate space hazards, creating among other things the Whipple bumper, a kind of hypervelocity impact shield that's designed to be as light as possible. You might guess that the biggest threats are the relatively bulky objects that make up space debris, which in low Earth orbit are bigger and more numerous than typical meteoroids. But meteoroids make up for their small size with high velocities. They tend to travel in the neighborhood of 12 to 72 kilometers per second when entering Earth's atmosphere and can penetrate shielding more easily than a comparatively sluggish piece of space debris can. A Whipple shield can protect a satellite from space junk hitting at speeds up to 18 km/s, but it's no match for faster meteoroids.

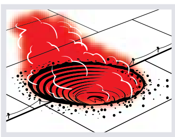
Given the danger they represent, it's downright shocking how much remains unknown about meteoroids. Ironically enough, what's best understood about them is how they act once they plunge into the atmosphere and become visible, when they are no longer a threat to spacecraft.

EVERY DAY, MORE THAN 100 BILLION meteoroids larger than one microgram enter Earth's atmosphere, traveling at more than 11 km/s. By the time these have made their way through the ionosphere (a plasma that extends between 70 and 1000 km above Earth's surface, its height depending on factors like solar cycle and time of day), the vast majority of meteoroids have been scoured away to nothing by the friction of the thickening atmosphere around them. As the mass is removed, it fans out behind the nucleus, forming a long glowing tail of plasma. These quick-moving flashes of light are commonly called shooting stars, although the correct term is *meteor*.

Meteor showers take place when Earth passes through the orbit of cometary particles. A shower is named after the constellation from which it appears to come. The Perseids seem to emanate from the constellation Perseus, the Leonids from the constellation Leo. Satellite operators are very familiar with these periodic barrages, and for the most part, they know how to protect their valuable space-borne assets.

Although it would be impossible to shield a satellite from a good-size cobble speeding along at many kilometers per second, such things are too rare to cause significant concern. The threats are the really small meteoroids—under 0.05 millimeter in diameter—which exist in much greater numbers. These interplanetary flyspecks aren't big enough to make flashes in the atmosphere visible to the naked eye;

## Sizing Up the Space-Debris Hazard

| | Event | Diameter (meters) | Impact energy (megatons) | Frequency |
|---|---|---|---|---|
|  | Shooting star | 0.00006 | $5 \times 10^{-16}$ | 1 second |
| | Brilliant fireball | 0.1 | 0.01 | 1 year |
|  | Aerial burst with modest damage | 25 | 1 | 200 years |
| | Local (10-km) devastation | 50 | 10 | 2000 years |
|  | Regional-scale devastation | 140 | 300 | 30 000 years |
| | Continental-scale devastation | 300 | 2000 | 100 000 years |
|  | Possible global catastrophe | 1000 | 100 000 | 700 000 years |
| | Global extinction | 10 000 | 100 million | 100 million years |

they're so tiny that spacecraft designers have not generally considered them much of a threat. But for satellites, they can be lethal. The damage these tiny grains inflict comes in part directly from the holes they make. Although they have little mass, they can travel extraordinarily fast. So even infinitesimal meteoroids can pack quite a punch.

Exactly how fast these meteoroids travel has been a bit of a mystery. For a long time, scientists simply assumed that the dominant population of submilligram meteoroids travel at around 20 km/s. But recent data gathered at high-power, large-aperture radar facilities (such as the Arecibo Observatory, EISCAT Scientific Association, Jicamarca Radio Observatory, and ARPA Long-Range Tracking and Instrumentation Radar, or ALTAIR) suggest the typical speed for meteoroids smaller than 50 micrometers is closer to 60 km/s. That's a pretty large correction.

We've also learned that the mass of a meteoroid, as well as its composition, depends in part on where it comes from. The prevailing wisdom has been that none of this material hails from beyond our own solar system, but I and others have recently done work that challenges this long-held belief. Although our conclusion courts controversy, we think that at least 4 percent may come from interstellar space, from the exploding stars that create pulsars and from other exotic locales, like the dust-enshrouded star Beta Pictoris, 63.4 light-years from our solar system. These are impressively distant origins for a little nub of matter that could easily blow a hole in a billion-dollar satellite. Interstellar meteoroids are faster than the fastest meteoroids from inside the solar system, entering Earth's atmosphere at speeds far greater than even the 72.8 km/s that most scientists currently define as the limit for a meteoroid originating outside our solar system.

BY NOW YOU'RE PROBABLY wondering why satellite designers can't just build better shielding and be done with it. Better physical shielding would help, of course. But it wouldn't do anything to protect spacecraft from a more subtle problem: the electrostatic discharges and electromagnetic pulses that accompany many impacts. The physics of these electrical effects is complicated. Even the notion that electro-

ILLUSTRATIONS: MCKIBILLO

## Kill Your Satellite

METEOROIDS HAVE TAKEN out more than a few spacecraft. In addition to Olympus and Landsat 5, other possible victims were the Small Expendable Deployer System (March 1994) and the Miniature Sensor Technology Integration (also March 1994).

Two types of electrical effects are associated with an impacting meteoroid: electrostatic discharges (ESD) and electromagnetic pulses (EMPs). An ESD—you'll know it as the garden-variety spark—occurs on a satellite when accumulated electric charge is suddenly discharged. It's the same principle by which you experience a mild electrical shock when you touch something after you've been walking across a carpeted floor. The satellite builds up charge simply by traveling in its orbit. Then, when the meteoroid smacks into the charged-up satellite, it acts as a flint to generate the spark.

An ESD is a serious problem for the many integrated circuits on board a satellite. These devices are made from semiconductors like silicon and gallium arsenide, materials that can sustain permanent damage from high voltages. The result of an impact could be a localized ESD, or a more serious problem such as a discharge of the whole satellite, depending on the material of the spacecraft. Some antistatic devices can help prevent static buildup, but no one knows how much buildup magnetic radiation from meteoroid impacts—tiny versions of the electromagnetic pulses given off by nuclear bombs—could be sufficiently energetic to destroy circuitry is controversial. But some NASA engineers suspect that exactly such an event led to the untimely demise of Landsat 5's gyros last year. Those who disagree think the culprit was the direct physical damage. But one thing is clear: Space scientists need to learn a lot more about meteoroids and the dangers they pose.

One way to study meteoroids is to observe how they shift the orientation of the satellites they strike. Scientists can use this simple method to detect meteoroid collisions, because the angular momentum of an object in orbit doesn't change without a reason. If a satellite's velocity shifts (and if other variables, like gravity, light pressure, and atmospheric drag are ruled out), the only logical conclusion is that something has hit it. It's easy to apply this technique with ALTAIR, because this radar can determine velocities with extreme precision. But even so, it's impossible to tell the difference between a satellite's collision with a large piece of relatively slow-moving space debris and a collision with a small but speedy meteoroid. Both could impart exactly the same change in momentum.

A better way to differentiate meteoroids from space debris—and to distinguish among the different kinds of meteoroids—is sorely needed. A technique that could do that would also help solve another, related problem: not being able to tell the difference between naturally occurring phenomena in our own ionosphere and man-made artifacts like launch vehicles or missiles. A good approach, I and many other space scientists believe, is to try to gauge the size and speed of all this space flotsam and jetsam by looking carefully at the plasma trails these objects create when they hit the atmosphere. With ALTAIR, that's a fairly straightforward exercise because the plasma reflects radio waves so well. Of course, you need to model the object's motions as it burns up to calculate how fast it was going in the first place. But if you do this right, you can also figure out its mass, density, and radius. This method is certainly better than just measuring the momentum transferred to satellites when they are struck. But the best strategy of all would be to observe meteoroid impacts up close from a vantage point in space.

To that end, I am collaborating with Andrew Kalman at Stanford to develop a satellite called MEDUSSA, which stands for Meteoroid and Energetics Detection for Understanding Space Situational Awareness. If it is built and flown as I hope, the MEDUSSA satellite will be able to study exactly what takes place when micrometeoroids and energetic particles slam into it.

With this information, engineers should be better able to design satellites to resist impact damage. Of course, there will still be run-ins with meteoroids and orbital debris that destroy spacecraft in mysterious ways, just as there are disasters with aircraft that defy explanation. But MEDUSSA would certainly help. And one day down the road, I anticipate that every satellite that gets lofted will contain a stand-alone unit to sense impacts and report their effects—even if they are extreme enough to disable the rest of the satellite. Think of it as a satellite "black box." Maybe then, we'll get a good picture of just all the unexpected things that can go wrong in space. ❑

*This article would not have been possible without the invaluable contributions of Stan Green.*

## Deep Impact


**METEOROID DAMAGE:** Pictured are the results of impacts on the Atlantis space shuttle payload bay door radiator, an insulation blanket on a module of the International Space Station, and the Hubble Space Telescope solar array.

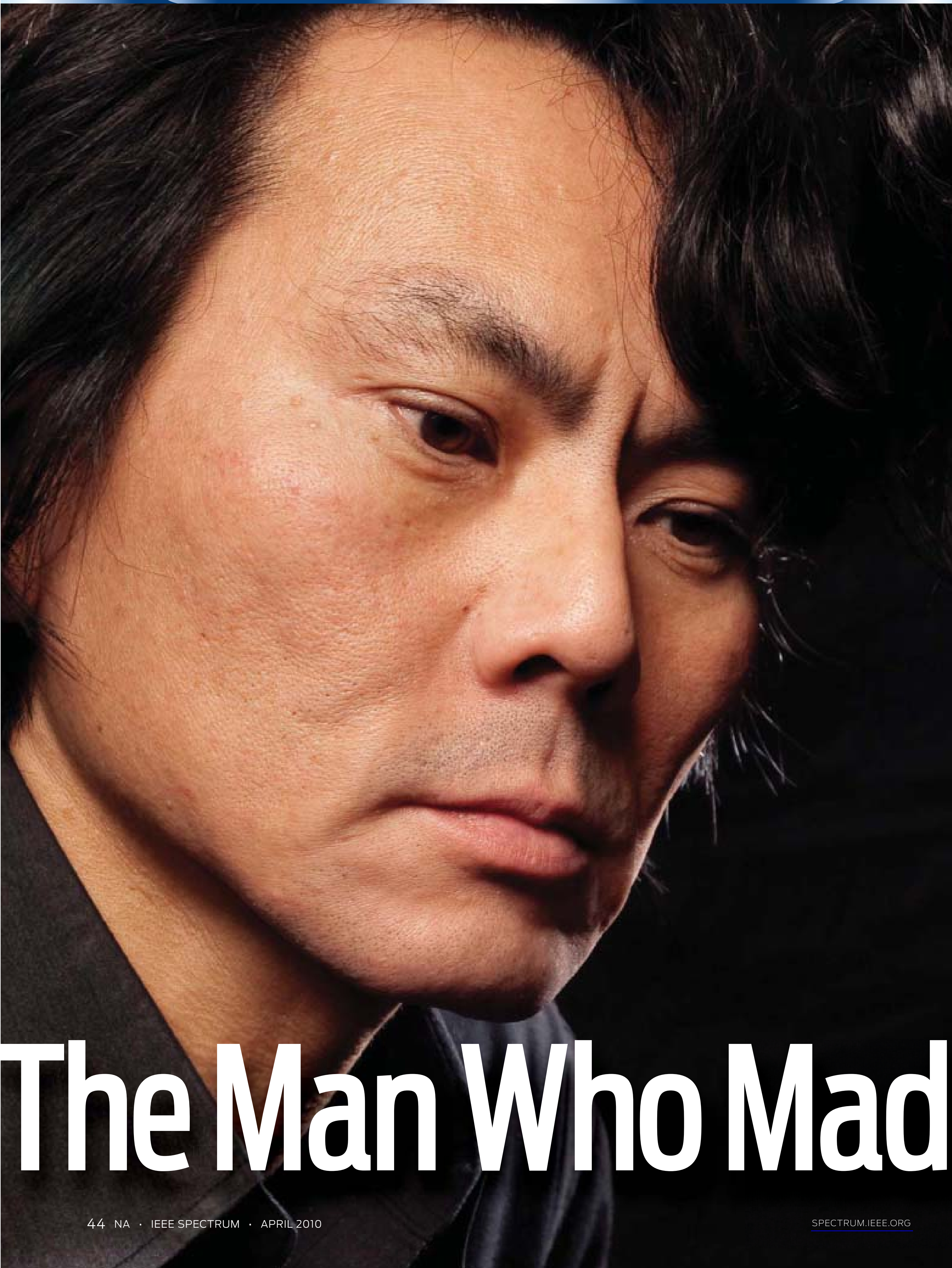
PHOTOS, FROM LEFT: NASA (2); ESA

BETWEEN 1992 and 2002, the space shuttles were assessed for meteoroid and debris damage 50 times. (Although the craft are assessed after each mission, there are more in-depth examinations if something is found to raise interest; think of it as the difference between regular Transportation Security Administration screenings and being pulled over for inspection.) After 62 missions, NASA inspectors found that the shuttle windows alone had been struck 1578 times and that 98 of these incidents led to damage that required repairs. Spectroscopic analysis of these 98 sites—in which inspectors looked at trace materials left on the collision site—revealed that orbital debris had caused 41 impacts. Eighteen were attributable to meteoroids; the causes of the other collisions are either unknown or left no samples in the impact craters. In low Earth orbit, where the shuttle operates, we expect human-made space debris to exceed the meteoroid population. But the space around satellites that lie farther out, in geosynchronous orbit, teems with equally large populations of space debris and meteoroids. By some estimates, in fact, meteoroids are more prevalent. —S.C.

they need to prevent because these effects have not been thoroughly studied.

Unlike ESDs, electromagnetic pulses (EMPs) occur when a colliding meteoroid vaporizes on impact and forms a plasma. In a collision, both the meteoroid and a fraction of the satellite evaporate and ionize, instantaneously forming a cloud of plasma. That plasma can then affect equipment such as the RF antenna on board.

The theory that meteoroid-induced EMPs cause catastrophic satellite failures is controversial and, at this writing, unconfirmed. However, researchers have been studying the plasma production associated with hypervelocity impacts for over 30 years. Enough unsolved satellite anomalies have taken place to make the case for EMPs as a damage mechanism. —S.C.



# The Man Who Mad



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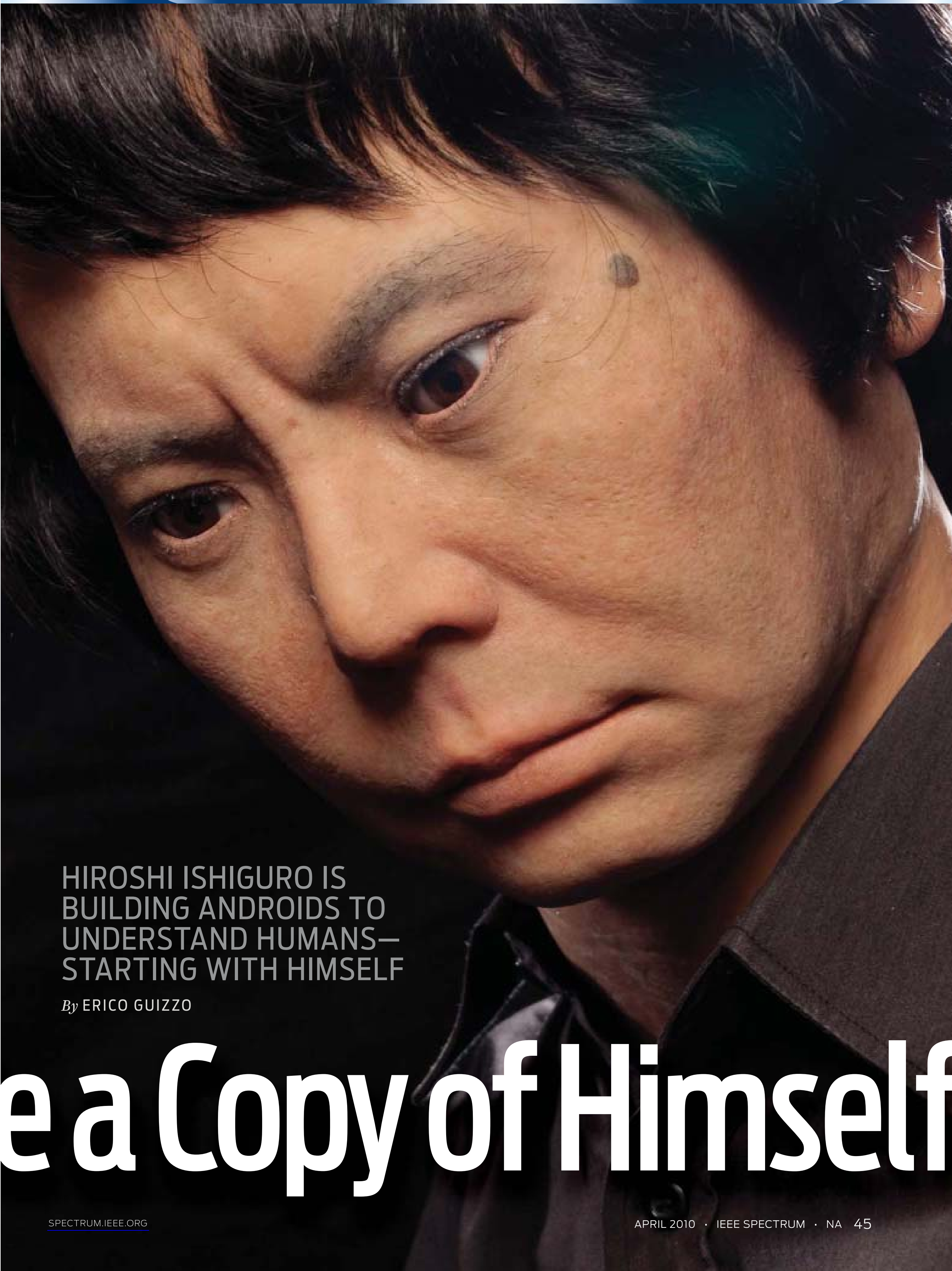

# e a Copy of Himself

HIROSHI ISHIGURO IS BUILDING ANDROIDS TO UNDERSTAND HUMANS—STARTING WITH HIMSELF

*By* ERICO GUIZZO

**SEEING DOUBLE:** Hiroshi Ishiguro and his robot twin [above and on previous pages] take a break.

THIS PAGE AND PREVIOUS PAGES: MAKOTO ISHIDA

**HIROSHI ISHIGURO,** a roboticist at Osaka University, in Japan, has, as you might expect, built many robots. But his latest aren't run-of-the-mill automatons. Ishiguro's recent creations look like normal people. One is an android version of a middle-aged family man—himself.

Ishiguro constructed his mechanical doppelgänger using silicone rubber, pneumatic actuators, powerful electronics, and hair from his own scalp. The robot, like the original, has a thin frame, a large head, furrowed brows, and piercing eyes that, as one observer put it, "seem on the verge of emitting laser beams." The android is fixed in a sitting posture, so it can't walk out of the lab and go fetch groceries. But it does a fine job of what it's intended to do: mimic a person.

Ishiguro controls this robot remotely, through his computer, using a microphone to capture his voice and a camera to track his face and head movements. When Ishiguro speaks, the android reproduces his intonations; when Ishiguro tilts his head, the android follows suit. The mechanical Ishiguro also blinks, twitches, and appears to be breathing, although some human behaviors are deliberately suppressed. In particular, when Ishiguro lights up a cigarette, the android abstains.

It's the perfect tool for Ishiguro's field of research: human-robot interaction, which is as much a study of people as it is of robots. "My research question is to know what is a human," he tells me between spoonfuls of black sesame ice cream at an Osaka diner. "I use very humanlike robots as test beds for my hypotheses"—hypotheses about human nature, intelligence, and behavior.

Robots, Ishiguro and others say, are poised to move from factories into daily life. The hope is that robots will one day help people with a multitude of tasks—they'll do household chores, care for the elderly, assist with physical therapy, monitor the sick at hospitals, teach classes, serve cappuccinos at Starbucks, you name it. But to be accepted in these roles, robots may have to behave less like machines and more like us.

Researchers have, of course, long been interested in making robots look and act more like human beings. Among the most notable efforts in this regard are Waseda University's Wabot, MIT's Cog, NASA's Robonaut, Sarcos's Sarcoman, the Toyota partner robots, Japan's METI HRP series, Sony's Qrio, and perhaps most famous of all, Honda's Asimo.

These robots are all mechanical looking, Ishiguro says, but our brains are wired to relate to other humans—we're optimized for human-human, not human-Asimo, interaction. That's why he builds robots that look like people, as part of his work at the Advanced Telecommunications Research Institute International, known as ATR, where he's a visiting group leader. To describe an android copy of a particular individual, he coined the term "geminoid," after *geminus*, which is Latin for twin. He named his mechanical brother Geminoid HI-1.



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By building humanlike robots Ishiguro hopes to decipher what the Japanese call *sonzaikan*—the feeling of being in the presence of a human being. Where does the sense of humanness come from? And can you convey those qualities with a robot?

The idea of connecting a person's brain so intimately with a remotely controlled body seems straight out of science fiction. In *The Matrix*, humans control virtual selves. In *Avatar*, the controlled bodies are alien-human hybrids. In the recent Bruce Willis movie *Surrogates*, people control robot proxies sent into the world in their places. Attentive viewers will notice that Ishiguro and the Geminoid have cameo roles, appearing in a TV news report on the rapid progress of "robotic surrogacy."

Ishiguro's surrogate doesn't have sensing and actuation capabilities as sophisticated as those in the movie. But even this relatively simple android is giving Ishiguro great insight into how our brains work when we come face to face with a machine that looks like a person. He's also investigating, with assistance from cognitive scientists, how the *operator's* brain behaves. Teleoperating the android can be so immersive that strange things happen. Simply touching the android is enough to trigger a physical sensation in him, Ishiguro says, almost as though he were inhabiting the robot's body.

"Like all Dr. Frankensteins of literature, he's raising some deep, powerful questions about our humanity and our creations, and it's scary, but it's also important that we confront these questions, and he's doing that not in the realm of fiction but in the laboratory," says IEEE Fellow Ken Goldberg, a robotics professor at the University of California, Berkeley. "We're going to learn something about machines—but even more about ourselves."

Hiroshi Ishiguro stomps on the accelerator. The black Mazda RX-8 roars onto the highway, the heavy-metal Scorpions blasting from the speakers. We're driving to Osaka University's Toyonaka Campus. Ishiguro is wearing aviator sunglasses, black polyester pants, a black vest on top of a black shirt, along with a black belt, socks, and shoes.

"Give me question," he says, his eyes fixed on the road.

I ask whether he always dresses in black.

"Why do you change your clothes?" he says. "Do you change your name? So why do you change your clothes? Name is identity. Face is identity. But the majority of your [appearance] comes from your clothes. You should not change your clothes. Do you agree?"

I meekly suggest that all-black attire might get a bit hot in the summer.

"We have air conditioners," he says. "Next question."

For an academic, Ishiguro lives a frantic existence. He works at four labs, oversees some 50 students, is a cofounder of a robotics start-up, and constantly travels to conferences around the world. No wonder he needs a copy of himself.

Ishiguro, who is 46, started building robots more than a decade ago, after abandoning the idea of becoming an oil painter. One of the first robots he helped put together, Robovie, looked like a trash can with arms. Another robot he worked with, Wakamaru, developed by Mitsubishi Heavy Industries, resembled an overgrown insect. People had mixed reactions to those robots, and that got him thinking about how crucial appearance is to communication. And yet, he realized, the connection hadn't been properly investigated.

**BEHIND THE CURTAIN:** Ishiguro teleoperates his android using a computer that captures his voice and facial expressions.

PHOTO: ATR INTELLIGENT ROBOTICS AND COMMUNICATION LABORATORIES

Indeed, consider that the world population of industrial and service robots is about 8.5 million, according to some estimates. That includes manufacturing robots, palletizing robots, surgical robots, bomb-disposal robots, milking robots, meat-handling robots, underwater and aerial robots, some 4 million home vacuum cleaners, and one that cleans the Louvre's glass pyramid. That's to say nothing about the vast assortment of robot dogs, dinosaurs, seals, and other robot toys. It's a fine bunch of helpful or at least entertaining hardware. Yet none of it matches the robots that science fiction promised the future would bring—Astro Boy, C-3PO, Data, Rosie, David, Number Six. Today's robots are closer to other appliances in appearance. And even the best of them aren't very good company.

Many roboticists believe this is going to change. They have visions of robots that will assist us, talk to us, even care about us. Social robots are coming to life in labs at MIT, Carnegie Mellon, Georgia Tech, and elsewhere. Though nobody knows yet what types of robots will become major applications (roboticists avoid the term "killer app," understandably), they may soon be among us.

But do they have to *look* like us?

Some roboticists I spoke to question whether humanlike androids are a good idea, or even necessary. One researcher, who asked not to be named because he collaborates with institutions with which Ishiguro is affiliated, says the Geminoid is "not very convincing—and a bit creepy." In some demonstrations, he notes, the android barely moves its eyes and lips, appearing catatonic. On YouTube, many commenters call videos of the Geminoid "scary" and "freaky." The tech blog Gizmodo included the android in its list of "10 Creepy Machines From Robot Hell."

Ishiguro is unfazed. He acknowledges that in some situations you don't need or want your robot to resemble a person. You don't need an android to vacuum your house if a saucer on wheels can do a better job. And a robotic assistant that helps an elderly person out of the tub probably shouldn't sport a human face.

He's also well aware that, although people might better connect with a robot when it resembles another human being, when it gets the nuances wrong it may seem more like a zombie or an animated corpse. The Japanese roboticist Masahiro Mori called this descent into creepiness, as lifelike appearance is approached but not attained, the "uncanny valley."

Ishiguro says the possibility that his creations might result in revulsion won't stop him from "trying to build the robots of the future as I imagine them." He is convinced that human-looking robots are a natural interface for humans to interact with and that the uncanny valley idea may be too simplistic to explain people's reactions to robots. We may simply come to accept life- *Continued on page 54*



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OPEN SESAME?

# The Middle East's first synchrotron is in peril

BY SANDRA UPSON

**SIGNS OF LIGHT:** Amor Nadji oversees the engineers striving to build a particle accelerator in Jordan. *PHOTO: JOSEPH ZAKARIAN*



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THREE YEARS AGO, Amor Nadji and three young engineers piled into a van in Amman, Jordan, and drove 30 kilometers northeast to the city of Zarqa. Their route took them past faded, sand-colored buildings and empty lots where sheep grazed on patches of grass and low brush.

The shops and apartment buildings gradually thinned out, and the van entered an industrial ghetto of warehouses. Behind one set of padlocked doors, about 100 plywood boxes and metal equipment racks stood coated in a thick layer of dust. Carefully packed away in those boxes was the collected hardware of a vintage synchrotron. The engineers' mission was to salvage the then-25-year-old particle accelerator and turn it into a first-rate machine. This supermicroscope, called SESAME (for Synchrotron-light for Experimental Science and Applications in the Middle East) would enable scientists from Jordan and nearby countries to investigate the atomic structure of different materials. The engineers' hope was that SESAME would revitalize Middle Eastern science and encourage friendly encounters between otherwise factious neighbors.



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But first they had to navigate the plywood labyrinth of dust and decay. A decade before, their particle accelerator had narrowly escaped being sent to a scrap yard in Germany. The machine, then called Bessy, had had a research program in full swing. But after the Berlin Wall fell in 1989 and the country reunified, the German government found itself paying for one synchrotron light source too many. By the end of the '90s Bessy faced dismantlement.

Around that time, four physicists working in Europe got a wild idea. CERN, the European Organization for Nuclear Research, had been built to encourage basic science after World War II and to help heal Europe's fractures. Maybe a defunct German synchrotron could do the same for the Middle East, the physicists thought. They asked Germany to donate Bessy to the region. The machine could help spur collaborations, they argued: Israeli scientists searching for new materials could run experiments next to Iranian biomedical researchers imaging proteins while Palestinian environmental scientists analyzed rock samples across the hall. The rest of the world, they pointed out, had built more than 60 such facilities, while the Middle East had none.

The four physicists got their approval. "It was one of the best [synchrotrons] in the world at the time," says Herman Winick, who was then on Bessy's board. "They were going to call a junkyard dealer and cut it up and sell it as scrap metal. I wanted to convince them that we should offer it as a gift." They set up a council to find Bessy a new home. Seven countries lobbied to get the machine, but Jordan won; its political regime was considered more stable and open to all visitors. The council recruited a fledgling staff, and the 13 young engineers were sent off to Europe for training.

In 2002, a ship pulled into Aqaba's harbor carrying the boxed-up Bessy, and Jordan got the makings of a synchrotron. But rebuilding a machine that was originally 64 meters in circumference is no simple affair. There was no place to set up the machine, and nobody to run it. Khaled Toukan, the chairman of the Jordan Atomic Energy Commission and SESAME's director, convinced King Abdullah II to donate a plot of land and build a hall for the synchrotron.

Two years passed before the team was ready to tackle the hardware. Nadji, SESAME's technical director, recalls facing the warehouse with trepidation. "This technology was completely new to this region, and my team was not very experienced," he says. "I suddenly had to be a specialist in everything." Among his colleagues, he alone had helped build a synchrotron before—Soleil, a new machine outside Paris. There, pristine laboratories full of oscilloscopes and probes enabled him to diagnose problems quickly and easily. Here, nothing of the sort existed. That didn't faze SESAME's staff. Arash Kaftoosian, an engineer from Iran, approached the project "like a puzzle," he says. "We used our imaginations to figure out how it all might fit together. But sometimes it seemed harder than if we were building it from scratch."

Indeed, SESAME's engineers, who hail from Iran, Pakistan, and the Palestinian territories, as well as Jordan, have been handed an almost impossible task. The equipment has become seriously dated, outstripped by the march of technological progress and aged by dust, heat, and time. Somehow, these young recruits must transform the mass of parts into a world-class laboratory so alluring that scientists from across the Middle East will set aside their grievances and build professional relationships at SESAME's workstations. The staff has had to do so in the face of apathy from their home governments and a mere trickle of funding for the new facility.

Nadji and his crew collected about 20 of the boxes from the warehouse in Zarqa and brought them back to Allan, a small community in the rolling, tree-covered hills outside Amman. A brand-new, empty white building on a bare plot of land awaited them. Despite the political and financial challenges, the team was optimistic. The project seemed difficult but straightforward—take a good, working machine and reconstruct it. None of them imagined that two years later, they'd just be getting started.

**ON A SUNNY MORNING** in May 2009, SESAME's engineers settle into their labs to finish soldering circuit boards for the synchrotron's new control system and power supply.

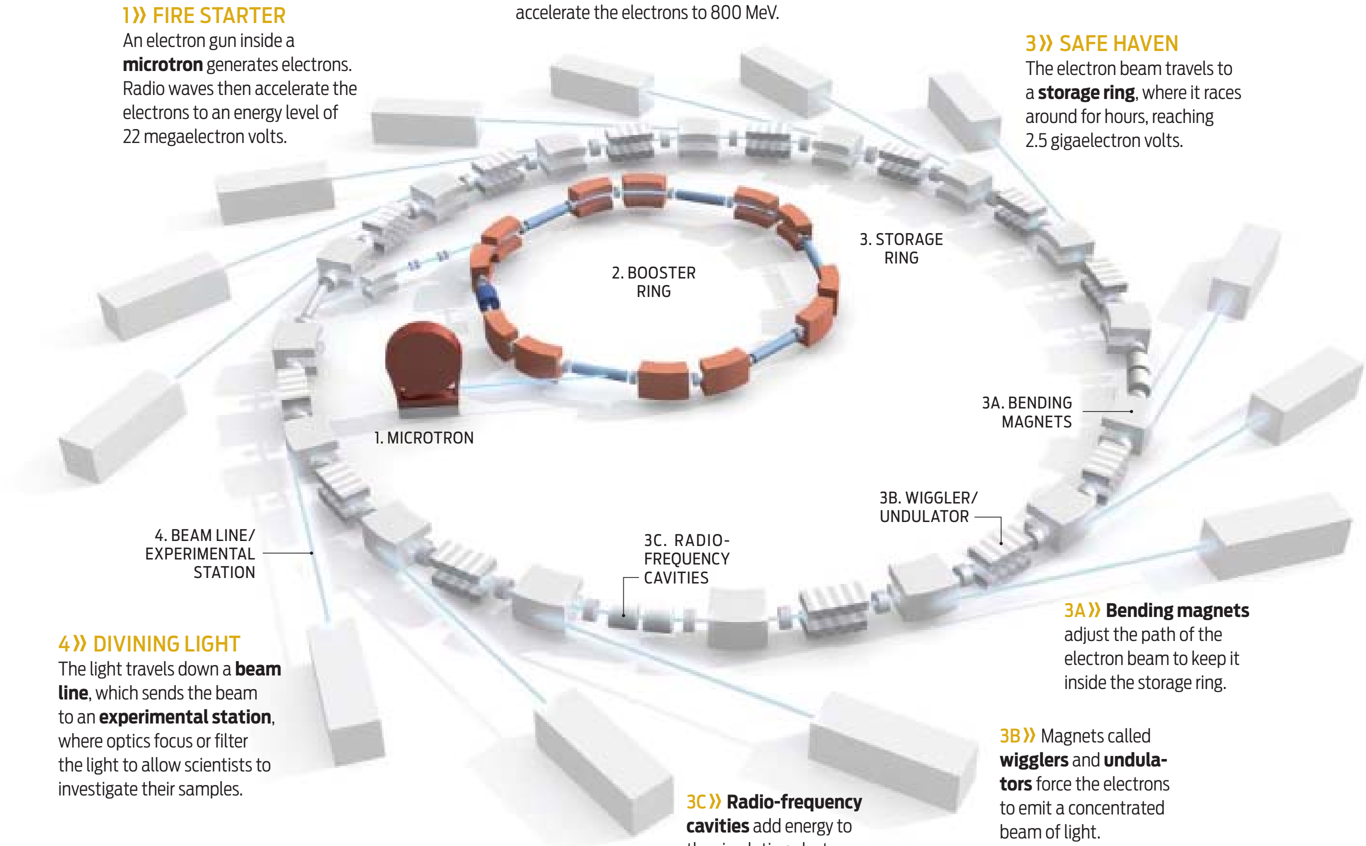
Outside, palm trees jut out of the tilled soil like sentries, and a scraggly patch of chrysanthemums bake under the cloudless sky. Students at the university next door peek through SESAME's gated fence as they wait for the local bus to arrive. A rooster belts out its morning salute.

Seadat Varnasseri, head of SESAME's power supplies and diagnostics, walks through the cavernous central hall and inspects a few boxes draped in plastic tarps. Rays of sun pour in through skylights and reflect off the shiny blue floor. The hall is clean and sleek, like a newly built Olympic arena.

Along the side of the main hall, a dozen bright orange cabinets stand on pallets amid crumpled sheets of plastic. Bundles of gray cords and wires droop from the cabinets, their ends cut off and dangling in midair. A vanilla-colored telephone receiver

**SYNCHROTRON DREAMS:** So far, SESAME's microtron [right] is up and running. The booster ring [left] is still under construction. *PHOTO: SESAME*

**SESAME, SOMEDAY:** If SESAME finds its funding, this giant microscope will generate beams of light for scientific experiments at 13 stations in SESAME's main hall. For now, though, the synchrotron has just a working microtron and the hardware for the booster ring, both shown in red.




perches on the side of one control center, and the stout bulge of a CRT screen protrudes from another.

Varnasseri sometimes comes here to scavenge a spare knob for a new diagnostic tool he's building. He admires the rows of square buttons lining a control panel, each with a label printed neatly in German. "I guess this could be a nice museum," says Varnasseri as he sizes up the racks, each one a carrot-colored relic that only the late 1970s could have produced.

The light streaming into the hall casts a soft gleam on the lone object in the center of the room: a maroon disc anchored upright like the face of a clock. The disc, 2.3 meters across, is the microtron, the ignition system for a synchrotron. The microtron's job is to inject a burst of electrons into the synchrotron's two nested, doughnut-shaped rings. Electrons will accelerate inside the first ring before entering the second one, where they will give off photons. These photons will have wavelengths far smaller than what ordinary microscopes can produce. By generating light with wavelengths of about $10^{-6}$ meters, a synchrotron can easily image a virus, and at $10^{-11}$ meters, researchers can see atoms.

The engineers have spent a year and a half trying to coax the microtron into producing an electron beam. It's a tricky process. First, an electron gun must fire: A 2-microsecond microwave pulse bombards a cathode, causing its surface to emit some electrons. These electrons must then enter a cavity that will be fed with 3-gigahertz radio waves to speed up the electrons. An electromagnet should generate a magnetic field that repels the electrons and causes them to spiral outward. The electrons should then race around inside the microtron, passing through the initial cavity and collecting more energy each time. After completing 42 laps, the electrons should emerge from the microtron as a 22-megaelectron-volt beam. (A megaelectron volt, by the way, is the unit of energy commonly used in particle physics, equivalent to $1.6 \times 10^{-13}$ joules.)

But the microtron has problems. For one, the device must be kept under a $10^{-3}$ pascal vacuum, but every cable and O-ring seal in the vacuum system has corroded with age. In addition, every circuit board in the control system contains obsolete transistors, so the crew has had to rebuild the control system from scratch. "Think about it—we had a 20-year-old computer control system. Computers change every week!" Varnasseri says with a grin, pointing at the dusty racks.

EMILY COOPER

**BEAM TEAM:** Bessy, the machine that was to become SESAME, bustled with activity and experiments in Germany before it was dismantled and sent to Jordan.
PHOTO: HELMHOLTZ-ZENTRUM BERLIN/BESSY II

To get even this far, the engineers had to decode the clues contained in the boxes they'd received from Germany. "At first we were in the dark," Varnasseri says. The staff had all the original paperwork for the hardware, but later changes and upgrades had been documented in stacks of handwritten notebooks—in German. They spent weeks sitting in a small, unheated warehouse next to SESAME's main hall, poring over the boxes. Nadji recalls their fingers stiffening with cold as they searched for clues to Bessy's last working configuration. "I had to convince myself that it was worth it to move the equipment to the main building," Nadji says. To put it more bluntly, he wasn't confident that the microtron could ever get built.

A picture of the original machine started to emerge from the electronics, magnets, and girders that surrounded them, and soon the assembly began for real. The engineers set up the microtron on a wooden bench in the main hall. They ran exhaustive tests on its vacuum pumps, radio-frequency generator, and electromagnets; all seemed to be in working order.

The staff now awaits a few missing pieces—new transistors for the electron gun and the diagnostic systems and a radiation monitor to help ensure that once the machine fires, the staff will be safe. Across the wide, sun-dappled hall, plywood boxes, each the size of a large refrigerator, hold the beam lines that will eventually deliver light to experimental stations. Top-notch synchrotron facilities donated the equipment in anticipation of the day when SESAME's brilliant rays will be aimed at samples brought in by biologists, archaeologists, and other investigators from across the Middle East.

What's missing is everything in between. The engineers have the electron source and the infrastructure to deliver photons to the experimenters. But they don't have a storage ring, the crucial apparatus needed to generate photons in the proper portions of the electromagnetic spectrum, a million times as bright as sunlight. Without a storage ring, SESAME is like a race car without an engine.

But the engineers keep working. The microtron is almost ready to be switched on. For the moment, the excitement of nearing that milestone overshadows the staff's deep uncertainty about the machine's ultimate fate.

AT 5 O'CLOCK ON 13 JULY, Nadji asks most of his staff to go home for the evening. It's time to test the microtron, and only the five people he needs to run the machine stay behind.

Nadji is nervous. They are about to find out whether their cautious reconstruction mimics Bessy closely enough to work. Maher Attal, an accelerator physicist from the Palestinian territories, sets up the microtron using the parameters they have on file. He triggers the electron gun. Nothing happens.

Perhaps something went wrong with the electromagnet, they think, so they turn its power supply off and back on again. They adjust the frequency of the radio waves entering the accelerating cavity—up, down, up some more, down some. Each adjustment changes the amount of energy transferred to the electrons and alters their orbits. They take a closer look at the deflection tube, which shields the electrons from the magnetic field to temporarily straighten out their path. They move the tube inside the microtron. By about 7 o'clock, the team decides that the electron gun isn't sending electrons hurtling through the deflection tube. Why not?

Two more hours go by. Darweesh Foudeh, a radio-frequency engineer from Jordan, swaps out a few burned-out transistors. Then Nadji realizes that the electromagnets have probably warped over time, so the settings used by Bessy's last operators won't work. Deviations in the magnetic field inside the microtron are probably causing electrons to fly off their intended path. So Attal adjusts the trim magnets, which are corrective coils that can compensate for small irregularities in the main magnetic field.

"At the end of the microtron, we put a fluorescent screen and a camera," Nadji recalls. The camera, sitting outside the microtron, points directly at the screen. At 12:34 a.m., a splotch materializes on it. The first electrons have emerged. Nadji remembers the moment vividly: "We could see on our monitors the shape of the beam. We finally knew. We created the beam, circulated it, and extracted it from the microtron."

They test it a few more times, to check that they can repeat the miracle. By 3 a.m. they have their proof. The microtron is producing a rectangular beam, approximately 2 by 4 millimeters, neat and clean and with no distortion.

The moment validates all the time and energy they've sunk into the touchy old machine. "To be honest, we wanted to show we were able to do it," says Kaftoosian, who is in charge of the radio-frequency group at SESAME. "I'm doing something new for my community. If I go to the United States and work on a synchrotron, okay, then you're working there. But you're not contributing to new things like SESAME, which is willing to go for peace and for solving political problems."

That day in July may well be the most exciting at SESAME so far. But they take no time to celebrate. The political infighting that the synchrotron was intended to help solve is now threatening to unravel its progress—and to undermine its very existence.

SESAME HAD NEVER BEEN AN EASY SELL. Back in the late '90s, when the European physicists Herman Winick, Gustaf-Adolf Voss, Sergio Fubini, and Herwig Schopper first dreamed up the idea of SESAME, they immediately faced obstacles. The gift they wanted Germany to make was valued at around $6 million or $7 million—but packing it up carefully, with the help of Russian specialists from Novosibirsk, would cost about $600 000. Schopper had less than four months to come up with the cash.

Schopper, formerly a director general of CERN, approached UNESCO first. After World War II, UNESCO had set up the framework for CERN, and Schopper believed the organization could also broker the initial talks between the Middle Eastern countries he hoped to bring on board. Together, Schopper and UNESCO's then assistant director-general for the natural sciences, Maurizio Iaccarino, quickly pulled together a coalition to sponsor SESAME. The group included Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority, and Turkey.

Getting the members to contribute their share of expenses proved harder. Schopper recalls collecting a mere $200 000. He pleaded with his German contacts to lower the tab, he says, "but the government had given me a hard condition. I had to come up with the money." In the end, UNESCO stepped in with the remaining $400 000. "The project would have collapsed without their support," Schopper says.

Since then, the synchrotron's directors have coaxed about $2 million out of its members for an operating budget that pays salaries for 22 people, keeps the building running, and allows small equipment purchases. But Nadji needs another $30 million to build the storage ring and finish the project. Bessy came with a storage ring, of course, but SESAME's team envisioned something far better. In order to court prospective users, in particular Middle Eastern biologists, the staff had agreed to upgrade the synchrotron to run at a higher energy of 2.5 gigaelectron volts, instead of Bessy's 0.8 GeV. The larger the circumference of the storage ring, the higher the energy it can accommodate—which means greater resolution for the images the synchrotron can produce. At 133 meters, SESAME's planned circumference is twice that of Bessy's.

With a ring that large, SESAME could generate hard X-rays and compete with other synchrotrons around the world. But generating such intense energy levels requires expensive and complex equipment: To control the electrons in that storage ring, specialized magnets must force the charged particles to maintain a circular path in a tight, compact beam. Other magnets, called wigglers and undulators, must deflect the electrons and cause them to lose energy, which they emit as light. The electrons should then pass through radio-frequency cavities to replace the energy they just lost.

So far, the members haven't paid. "I'm coming from Soleil, where the machine itself was maybe €150 million. Here we're talking €20 million," Nadji says, a note of frustration creeping into his voice. To him, the case for the storage ring is obvious. "Every year the demand at synchrotrons is always twice the opportunities," he explains, and so only half of the research teams that apply for time on a beam line actually get it. Many countries, including Brazil, India, Taiwan, and Thailand, have addressed the access problem by building their own synchrotrons.

But there's a bigger issue at work here, says Hafeez Hoorani, SESAME's scientific director and a research director at the National Centre for Physics at Quaid-i-Azam University, in Pakistan. "The more fundamental problem is how much Middle Eastern countries are investing in science," Hoorani says. According to data from UNESCO, Arab states spend, on average, 0.2 percent of their gross domestic product on research and development, while the world's average is 1.7 percent. (Israel is the exception in the Middle East, with 4.7 percent of GDP dedicated to R&D.)

Nadji estimates that SESAME's engineers have about a year of work left before they run out of things to do. They're now testing the booster ring, which accepts the electron beam from the microtron and accelerates it before transferring it into the storage ring. They hope to produce a beam that travels from the microtron out through the booster ring by the end of the year.

Reaching that landmark may be a mixed blessing. Without the storage ring, the talented young engineers will have nothing left to do, and Nadji fears that his dedicated, hardworking team will start to defect.

They would be departing just as the first signs emerge that SESAME is indeed becoming a worthy descendant of CERN. "For me the nicest thing is seeing people coming together through SESAME and seeing Palestinians and Israelis sitting and talking together," Hoorani reflects. Eliezer Rabinovici, a physics professor at Hebrew University, in Jerusalem, concurs. "As a string theorist, I work on parallel universes," he says. "I was always curious what a parallel universe was like, and now I know. I'm living in one when I go to SESAME meetings."

SESAME's situation may be about to change. Last month, Rabinovici talked Israel into pledging $1 million a year for five years—but only if four other members also do so. Two members have signed on already, and Sir Christopher Llewellyn-Smith, president of the SESAME council, is optimistic that others will also join in soon. Nadji says he'll continue to push his team to finish the job. "We've come this far," he says. "I have to believe we'll get there." ❑

# The Man Who Made a Copy of Himself

*Continued from page 47*

like androids as we're exposed to more of them and, in the future, rely on them for our care and other needs.

Or as he puts it in Phie Ambo's 2007 documentary *Mechanical Love*, "If we're short on people, why not make some?"

We're standing outside Osaka University's Intelligent Robotics Laboratory, which Ishiguro directs. It's a Sunday, the lab is empty, and we're locked out. Ishiguro can't recall the code of the entry lock and is on the phone with a colleague. When the door finally opens, robotic creatures great and small are everywhere—and they appear to be staring right at me. I ask about a diminutive android standing in a corner.

"That is my daughter's copy," Ishiguro says. He explains that the robot, built in 2001 and called Repliee R1, was based on his then 4-year-old daughter. It has nine DC motors in its head, prosthetic eyeballs, and silicone skin. Ishiguro says that the eyelids looked unnatural and that only the mouth moved, so the robot's facial expressions couldn't change much. When the neck turned, a lack of stiffness in the body would cause the robot to shake. People told him that it gave them a strange, eerie feeling. That includes the robot's master template—Ishiguro's daughter.

"She was scared very much," he says, "and almost cried." It took several meetings until she warmed up to her double.

Surely Ishiguro must have been staring into the abyss of the uncanny valley. His response was to attempt a flying leap over the chasm—to build a markedly better android. This time he modeled it after an adult. Ishiguro shows me the result.

"This is Repliee Q2," he tells me, almost as if introducing a friend. The android has long golden-brown hair, glossy lips, perfect skin, and 42 pneumatic actuators embedded in her petite body. Perched on a stool, she—er, the android—can talk about itself and sing Disney tunes. Ishiguro built it with help from the robotics firm Kokoro, which has considerable experience with animatronics. Kokoro engineers and Ishiguro's team worked particularly hard to duplicate a woman's facial expressions, blinking, and hand movements. And they wrote software to simulate involuntary movements like breathing and subtle head twitches.

"All humans have these," Ishiguro says, "unless they're dead."

For the 2005 World Exposition in Aichi, Ishiguro replaced the face, copying that of a famous Japanese newscaster, Ayako Fujii. Visitors lined up to talk to the robotic impersonator.

"An elderly gentleman came over and asked, 'Where's the android?' and he was standing right next to it," says Karl MacDorman, a former Ishiguro collaborator and now director of the Android Science Center at Indiana University–Purdue University, in Indianapolis. "Androids can press our Darwinian buttons—they are perfect tools to study how our brains work."

Despite its success in many regards, this android revealed a serious problem. The techniques of artificial intelligence remain too primitive to reproduce everyday human behavior, like the ability to sustain a conversation. So the robot's lifelike appearance proved deceiving: People expected more than it could deliver.

After some careful reflection on the problem, Ishiguro decided to shift his focus from autonomous androids to teleoperated ones. For that, he figured he'd start with a copy of a real person, someone he could trust and who'd be willing to become a guinea pig in long, tedious experiments. He'd reproduce himself.

Building on what he had done with Repliee Q2, Ishiguro added even more actuators to the Geminoid: 13 in the face, 15 in the torso, and 22 in the arms and legs. His team used a cast to make a perfect copy of his physique. They improved the body-control software to generate even finer motions and developed a computer vision system to synchronize the Geminoid's lips to the operator's.

**REPLICANTS:** Ishiguro's lifelike androids include a copy of his daughter [left] and a TV newscaster [above].

PHOTOS: LEFT, ATR INTELLIGENT ROBOTICS AND COMMUNICATION LABORATORIES; RIGHT: YOSHIKAZU TSUNO/AFP/GETTY IMAGES

So how did people react?

In the three years since completing the Geminoid, Ishiguro has tested the android using dozens of volunteers, colleagues, and students, as well as his wife and daughter. In controlled experiments, he observed that people may feel uneasy at first, but they quickly adapt, and most are capable of having a natural conversation with his replica. No one ran away from the android screaming in horror. He also showed that the Geminoid could act as a good salesman, that children were eager to play games with it, and that pet owners were particularly skilled at detecting its nonverbal cues.

His main conclusion is that in many situations people respond to the Geminoid in much the same way they do to other individuals. What's more, people who know him, Ishiguro says, could experience his personality and authority: The android, though not perfect, was able to convey *sonzaikan*—his presence.

"To look back at the trajectory of androids in his lab, the progress is striking," says Andrea Thomaz, a robotics professor at Georgia Tech who is familiar with Ishiguro's work. The exciting part about his and others' work on androids, she adds, "is that it forces us to more fully understand human behavior at every level."

For Ishiguro, having a robot clone has practical uses as well—such as being in two places at once. Most of the time the Geminoid resides at ATR, in Kyoto, an hour's drive from Osaka, so Ishiguro uses the robot to attend meetings there.

"Very convenient," he says with a smile. "The problem is I can't get salary from ATR if I use the Geminoid. Therefore they still make me go there."

IT'S LATE at night, and Ishiguro sits in his Osaka University lab. He's teleoperating the Geminoid, which is lounging 9000 kilometers away at a café in Linz, Austria. The android is there as part of the Ars Electronica festival. Ishiguro is chatting with a group of kids who'd taken notice of the robot. Then a boy pokes the android's face.

"Yahh, don't touch to my face," Ishiguro yells. The kids laugh.

But what just happened was quite profound. Ishiguro says that when the kid poked the robot's face, he felt a tingle on *his* cheek—even though nothing was attached to his face. For an instant, Ishiguro's brain mistook his body for another—in Austria.

Ishiguro has experienced this many times in different settings, all with the same result: He feels as though the touch were real. He believes the phenomenon stems in part from observing the synchronization of the android's head and lips with his own. When Ishiguro uses the Geminoid, he sees video from external cameras that show the robot's field of view and also its face. Because he is watching the robot's lips move as he speaks and seeing its head move when he turns his own neck, Ishiguro's brain starts to treat the robot as an extension of his own body.

Even more surprising, Ishiguro says that when *other* people teleoperate the Geminoid, after a while they, too, may experience the "phantom poke." This means that an android doesn't even have to look like you for you to think of its body as your own!

Peter W. Halligan, a psychology professor at Cardiff University, in Wales, who is not involved in the Geminoid project, says the phenomenon "sounds fascinating." He notes that a possible explanation is that humans have mirror neurons that fire both when a subject is touched and when the same subject observes another being touched, in this case on the face. In normal situations, the sensation is suppressed. Is the act of teleoperating a robot tricking the brain?

Indeed, the brain fills in many gaps in the signals our sensing organs send to it, and our sense of embodiment is more malleable than most people think. Recently, Swedish researchers showed that when presented with certain visual cues, subjects wearing head-mounted displays could experience other people's bodies—or a mannequin's—as their own.

Ishiguro is collaborating with cognitive scientists to investigate the phenomenon. He's planning to use brain scans to find out what happens inside the operator's head when the Geminoid gets poked. He believes his results will show humans can easily adapt to robotic bodies.

Whether each of us will have a geminoid in the future remains to be seen. But lifelike androids are already helping Ishiguro and others explore some of the pressing questions in human-robot interaction. What do people expect from robots? What social behaviors should they exhibit? And how do we get their look right? In the coming years, researchers will have to answer these questions to come up with design principles for building the next generation of social robots.

Ishiguro, for his part, believes that robotic telepresence will become a major communication medium over the next decade. Eventually, he speculates, humanlike robots will become truly integrated into society—not just for factory automation or as labor-saving devices but as replacements for someone's physical presence. A future where androids may become so advanced that we're unable to distinguish them from ourselves doesn't frighten Ishiguro.

"Humankind is always trying to replace human abilities with machines. That's our history," he says. "I'm doing the same thing. Nothing special." ❑

SLIDESHOW *For more photos of Ishiguro's robots, go to* http://spectrum.ieee.org/geminoid.



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# Porsche Panamera

*Continued from page 31*

for sharper control. That air suspension also lets the driver raise or lower the car's body, including a maximum height to clear steep driveways or curbs or ultralow for high performance.

The acronym soup continues with a sophisticated active all-wheel-drive system (Porsche Traction Management, or PTM) and Porsche Dynamic Chassis Control (PDCC), which combines active antiroll bars with an electronic rear differential to keep the Panamera's body amazingly flat when cornering at high speed. The antiroll bars feature hydraulic swivel motors that send pressurized oil to either side of the car, creating counterresistance on the body as cornering forces build. The rear differential divvies power among the wheels according to their relative traction and accelerative forces. In steady cruising, the roll bars are decoupled, boosting ride smoothness by allowing each wheel to respond more sensitively to bumps.

All a driver needs to know is that the Panamera makes the term *four-door sports car* a reality, not a marketing gimmick. About as wide as a Mercedes S-Class and topping 1900 kg, the Panamera Turbo is no Lotus lightweight. Yet crank up the Sport Plus setting and the Panamera boggles mind and body alike, cracking the 1 *g* barrier of lateral acceleration, among other feats. It's also a license shredder, so luxurious and accommodating that it's forever sneaking past 100 mph when you meant (honestly, officer) to go 75, making this Porsche the ultimate carpooling machine. For the autobahn, anyway. *—Lawrence Ulrich*

# BMW X6 M

*Continued from page 35*

formidable Evo get eaten alive by the hulking Bimmer—to the shocking tune of 10 seconds per lap. BMW engineers have also seen their most powerful M model confound expectations: At the legendary Nurbürgring course in Germany—for decades a testing benchmark for the world's production and racing cars—the X6 M covers the 20.8-km (12.9-mile) circuit faster than the previous-generation M3 sedan.

The X6 M's downside, as you might expect, is pitiful fuel economy. This 2.4-metric-ton Bimmer slurped premium unleaded at 1.6 liters per 100 kilometers (14 miles per gallon) during my testing, with the Environmental Protection Agency pegging official mileage at 12 and 17 mpg in city and highway use, respectively.

Yet ultimately, type A drivers with the means to buy this US $89 000 mildly sociopathic monster will also be the type to brush off social critics, preferably by tromping on the gas. Questions of relevance aside, those owners will be rewarded with an SUV of which NASA might be proud—for both velocity and technology. *—Lawrence Ulrich*

# Aptera 2e

*Continued from page 37*

is also pledging to make it possible for third parties to develop apps that add functions beyond those that come with the car, and Aptera expects drivers to cooperate by swapping tips and even to compete for the best energy-efficiency ratings. Regrettably, my test car had almost none of those features, with its onboard computer simply sending data to test equipment.

It must be said that the company has had financial problems and that it has deferred the car's launch several times. But this is a review of a technical achievement, not an appraisal of a business plan. If deliveries of the 2e do launch on schedule, Aptera plans to start work on a plug-in hybrid model that will have a smaller battery pack combined with a small, highly efficient combustion engine to serve as a range extender for trips beyond the 2e's guaranteed range of 160 km (100 miles).

But that's still in the future; for now, all hands are concentrated on finishing development of the 2e. If the company can deliver production vehicles to the first of more than 4000 customers who've put down deposits, it will have beaten the odds and created a car that flies down the road like an airplane, powered by the swift silence of electricity. *—John Voelcker*



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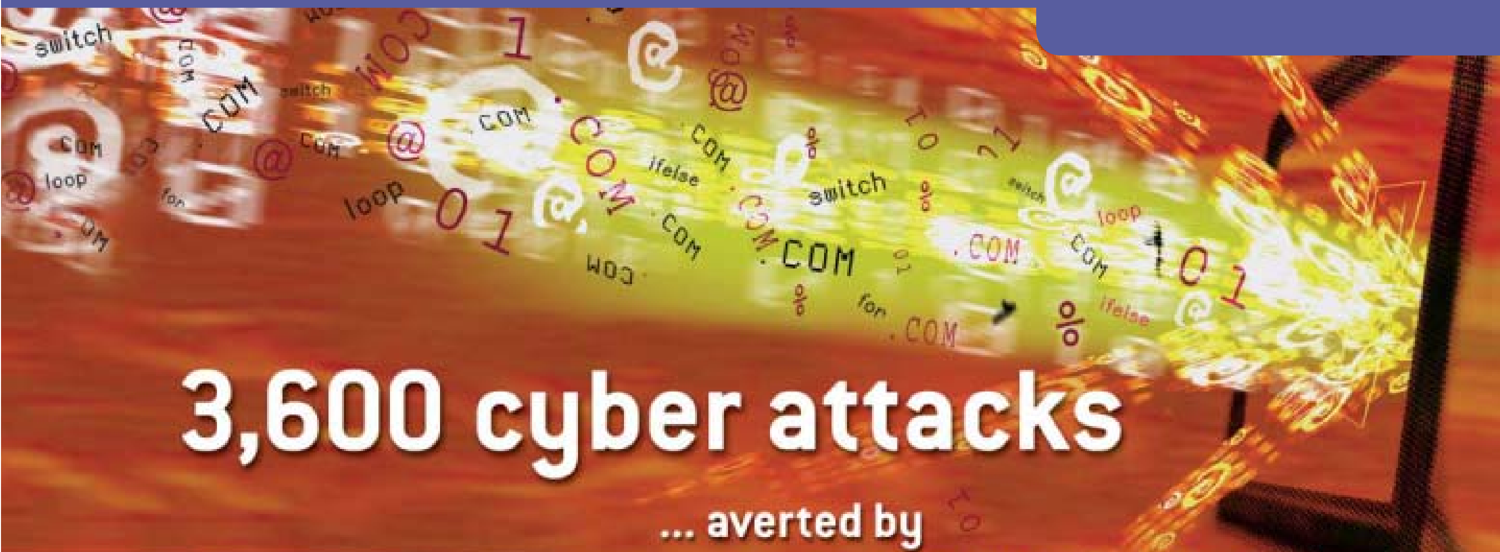
# NATIONAL SECURITY AGENCY NSA



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The Electrical Engineering Department at the

# University of Washington

SEEKS AN OUTSTANDING INDIVIDUAL to fill the recently endowed **Donald W. and Ruth Mary Close Professorship in Electrical Engineering** with a focus on electric energy.

THE IDEAL CANDIDATE will be an internationally renowned EE faculty in the field of Electric Energy with an emphasis in one or more of the following areas:

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- **Advanced automation (reliability and efficiency), and/or**
- **Environmentally-based operation and optimization.**

The candidate should hold a terminal degree, have an interdisciplinary background and would be expected to interact with the new College of the Environment as well as other departments in the College of Engineering and other colleges in the University. It is anticipated that the appointment will be at the level of Full Professor with Tenure, commensurate with the applicant's qualifications. All offers will be contingent on budgetary approval by the University.

UW HAS THE HIGHEST LEVEL of federal funding of all public universities, and the second highest among all universities in the nation. The Electrical Engineering Department currently has 40 tenure track faculty (34 men / 6 women). External research expenditures of the department in 2008-2009 were nearly $14M (see *www.ee.washington.edu*). The department is committed to outstanding teaching, research, and service.

PLEASE SUBMIT YOUR RESUME, list of publications, statement of research and teaching interests and goals, and the names and addresses of at least five references on our website: *http://www.ee.washington.edu/facsearch/*.

Applications will be accepted until May 15, 2010, or until the position is filled. For any administrative issues related to the search, please contact Sarah Espe (*assist_to_chair@ee.washington.edu*).

THE UNIVERSITY OF WASHINGTON is building a culturally diverse faculty and strongly encourages applications from female and minority candidates. The University of Washington is the recipient of a 2006 Alfred P. Sloan Award for Faculty Career Flexibility and a 2001 National Science Foundation ADVANCE Institutional Transformation Award to increase the advancement of women faculty in science, engineering, and mathematics (see *www.engr.washington.edu/advance*). The University of Washington is an Equal Opportunity, Affirmative Action Employer and is responsive to the needs of dual-career couples.

# Electrical Engineer
# Cause & Origin Failure Analysis
# Louisville, Kentucky

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(This opportunity is based in Louisville, KY)

DONAN ENGINEERING
FORENSIC ENGINEERING & FIRE INVESTIGATION

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NSU
NORFOLK STATE UNIVERSITY

Department of Engineering
**Department Chair**

**POSITION:** The College of Science, Engineering and Technology at Norfolk State University invites nominations and applications for the Department Chair position in Engineering.

**RESPONSIBILITIES:** The successful candidate will manage the Engineering Department, including oversight of undergraduate and graduate programs in Electronics and Optical Engineering. The search committee will seek out candidates that possess outstanding communications skills, experience in the management and oversight of academic programs and research activities and academic faculty and staff, a working knowledge of on-going innovations in engineering education, and the potential to inspire students. Candidates should also be knowledgeable about funding structures in engineering education, including avenues for the realization of research funding through government and private organizations.

**QUALIFICATIONS:** The candidate must have a Ph.D. degree in Optical Engineering, Electrical Engineering, Materials Science, or a related field. The successful candidate should have a strong record of research accomplishments. The Department is particularly interested in candidates with experience in the development and use of cleanroom facilities and the development and application of optical sensors, systems, and materials. Applicants with industrial experience and/or documented college-level teaching experience are strongly preferred.

**SALARY/RANK:** Commensurate with qualifications and experience

**EFFECTIVE DATE:** Fall 2010

**APPLICATION PROCEDURE:** Candidate should submit a letter of interest outlining qualifications and related experience, a statement of your teaching philosophy, current curriculum vita, and three letters of reference to:

Dr. Frances Williams
Chair, Engineering Search Committee
Norfolk State University
700 Park Avenue
Norfolk, VA 23504
E-mail – ***fwilliams@nsu.edu***

COLLEGE OF SCIENCE, ENGINEERING & TECHNOLOGY

Individuals with disabilities and requiring accommodations in the application process should call the Office of Human Resources (757) 823-8160 (Voice) / (757) 823-2876 (TDD).

UMASS AMHERST

# Post-CMOS Nanodevices and Systems

The Department of Electrical and Computer Engineering at the University of Massachusetts Amherst invites applications from candidates for a tenure-track position in experimental Post-CMOS Nanodevices and Systems at the Assistant Professor level starting September 2010. The department seeks to complement existing work in nanodevice simulation, information processing in nanosystems, nanocircuit manufacturing, and nanocomputing architectures with experimental nanodevice research that will contribute to the ultimate realization of nanocomputing systems.

Candidates must have an earned doctorate in ECE or related field at the time of appointment, demonstrated research expertise in the fabrication and characterization of emerging nanoelectronic devices for post-CMOS device technology and computing, and interest in cross-cutting issues related to the realization of nanocomputing platforms using scalable nanomanufacturing techniques. The candidate will be expected to develop a strong externally-funded research program, must be committed to teaching undergraduate and graduate courses in electronic and nanoelectronic device physics and fabrication, and should have an understanding of diversity issues and their educational importance. Interest in contributing to the development of multidisciplinary nanotechnology education programs is desirable.

**The search committee will begin reviewing applications on April 16, 2010. The search will continue until the position is filled. Appointment is contingent upon funding. Interested applicants should send a CV, statement of research and teaching interests, and the names and addresses of at least four references to: nanosearch@ecs.umass.edu.**

*The University of Massachusetts is an Affirmative Action/ Equal Opportunity Employer. Women and members of minority groups are encouraged to apply.*

RUTGERS
School of Engineering

**The Department of Electrical and Computer Engineering** anticipates multiple faculty openings for tenure-track, assistant professor positions in Computer Engineering areas. Outstanding applicants with relevant experience may also be considered at the associate or full professor level.

Core areas of interests include *computer architecture* (focus on energy efficient architectures); c*omputer systems* (focus on massive data sets and data-intensive computing); *computational science and engineering* (focus on cloud/ grid computing); *pervasive computation* (focus on networked cyber-physical systems); *human-machine interfaces* (focus on real-time multi-modal interactions); *internet architecture* (focus on next-generation network protocols and testbeds/cyber-infrastructure).

In addition, the School of Engineering is anticipating significant growth in other important areas including *health, energy, transportation*, and *materials and devices.* The ECE Department encourages excellent candidates in these interdisciplinary thrusts to apply for possible consideration as the positions become available.

A Ph.D. in EE, CE, CS or a related field is required. Responsibilities include teaching undergraduate and graduate courses and establishing independent research programs. Excellent facilities are available with opportunities for research affiliation with various university centers such as Center for Autonomic Computing (CAC), Wireless Information Network Laboratory (WINLAB), etc., as well as with local industry. Qualified candidates should submit a CV, statements on teaching and research, and names of three references to the URL:

**http://faculty.engr.rutgers.edu**.

Applications may also be submitted by mail to: Chairman, Department of Electrical and Computer Engineering, Rutgers University, 94 Brett Road, Piscataway, NJ 08854-8058.

The review process will begin immediately and will continue until the positions are filled. Information about the department can be found at

**http://www.ece.rutgers.edu**.

*Rutgers is an Equal Opportunity/Affirmative Action Employer.*

WSU
WICHITA STATE UNIVERSITY
COLLEGE OF ENGINEERING

The Department of Electrical Engineering and Computer Science at Wichita State University has an open tenure-eligible faculty position at the assistant professor level in the areas of computer architecture. Duties and responsibilities include teaching undergraduate and graduate courses, advising undergraduate students, supervising MS and PhD students in their theses and dissertations, obtaining research funding, conducting an active research program, publishing the results of research, and actively participating in professional societies.

*Complete information and qualifications can be found on our website*

**www.eecs.wichita.edu**

Wichita State University, with about 15,000 students, is located in Wichita, Kansas, the largest city in Kansas and the industrial center of the state. The greater Wichita area has a population of about 500,000 and is home to several aircraft manufacturers, many aircraft-supporting industries, and information technology companies. Wichita tops Newsmax Magazine's ranking of "Most Uniquely American Cities", and ranks sixth in Forbes' "America's best bang-for-the-buck cities".

To ensure full consideration, the complete application package, consisting of a vita with cover letter, a list of three references, and teaching and research philosophies, must be received by May 1, 2010. Applications are to be submitted online at **http://jobs.wichita.edu**. Applications will be continuously reviewed after that date until determinations are made with regard to filling the positions. Offers of employment are contingent upon completion of a satisfactory criminal background check as required by Board of Regents policy.

**Wichita State University is an equal opportunity and affirmative action employer.**



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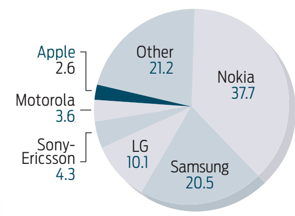
# the data


SOURCE: APPLE (APPLE'S FISCAL YEAR ENDS 30 SEPTEMBER)

**4Q 2009 MOBILE PHONE SHIPMENTS**
WORLDWIDE (PERCENT)




**4Q 2009 SMARTPHONE SHIPMENTS**
WORLDWIDE (MILLIONS)

| | |
|---|---|
| Nokia | 20.8 |
| RIM | 10.7 |
| Apple | 8.7 |
| HTC | 3.4 |
| Motorola | 2.1 |
| Palm | 0.9 |
| Other | 5.7 |

*SOURCE: ABI RESEARCH*

# iPods and iPads: Better Than Diamonds

IS THE Apple iPad a computer or an entertainment device? If Apple's recent history is a guide, it's the latter. After all, Apple is no longer mainly a computer manufacturer.

Last year, computer sales accounted for less than a third of Apple's total revenues, while more than half came from iPhones, iPods, and sales of music-related products and services.

Apple is better off as a phone and entertainment company anyway—that's where it has room to grow. As Joe Wilcox of Betanews reported in February, Apple already has 90 percent of the retail market for premium PCs (defined as costing more than US $1000), according to NPD Group, a market research firm in Port Washington, N.Y. By contrast, Apple has only a tiny share of the phone market.

Michael Morgan, an analyst at ABI Research, in Oyster Bay, N.Y., says that of the 336.5 million phones he estimates were sold in the fourth quarter of 2009, only 8.7 million were iPhones. Even looking only at smartphones, Apple's share was about 17 percent.

How far has Apple come from its computer origins? Consider its stores, at nearly 300 strong by the end of 2009. No other computer maker has a similar chain. Then again, neither does anyone else: By some measures Apple is the most successful retailer in the world. According to a story on Bloomberg.com last year, the company's famous glass cube store on Fifth Avenue in New York City has twice the sales per square foot of diamond retailer Tiffany's flagship just down the street. Of course, the cube is open 24 hours a day, so you can buy an iPod—and now an iPad—well before breakfast. —*Steven Cherry*

*ILLUSTRATION: EMILY COOPER*