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My Genome

A QUICK AND AFFORDABLE TEST TOLD ME LOTS OF THINGS I WANTED TO KNOW ABOUT MY HEREDITY—**AND ONE THING I DIDN'T**

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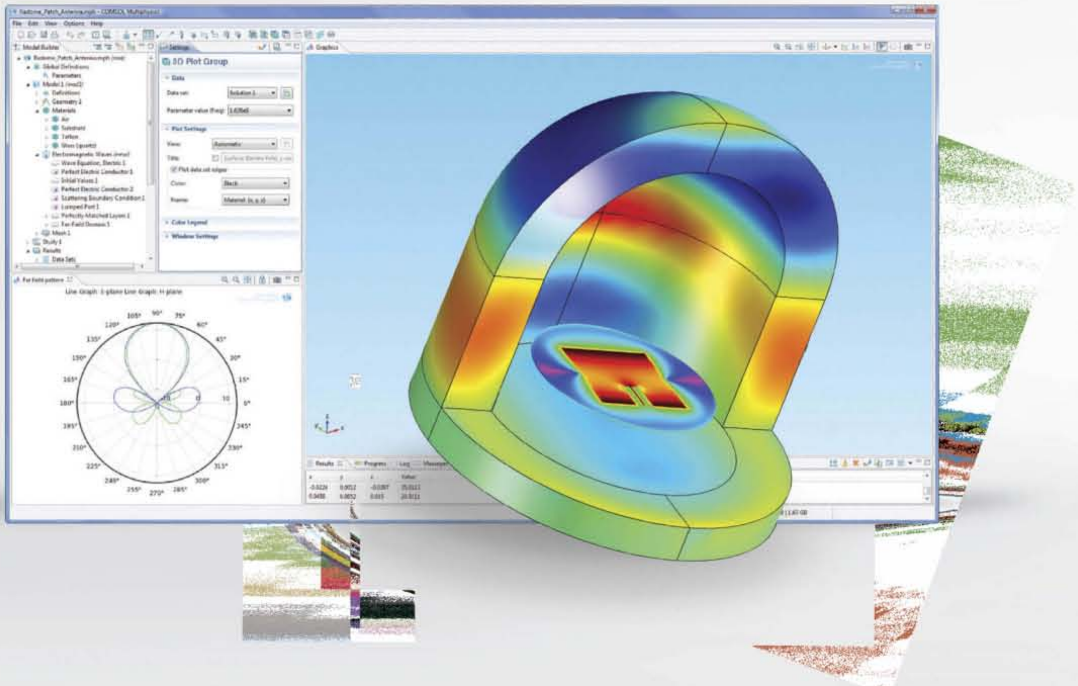

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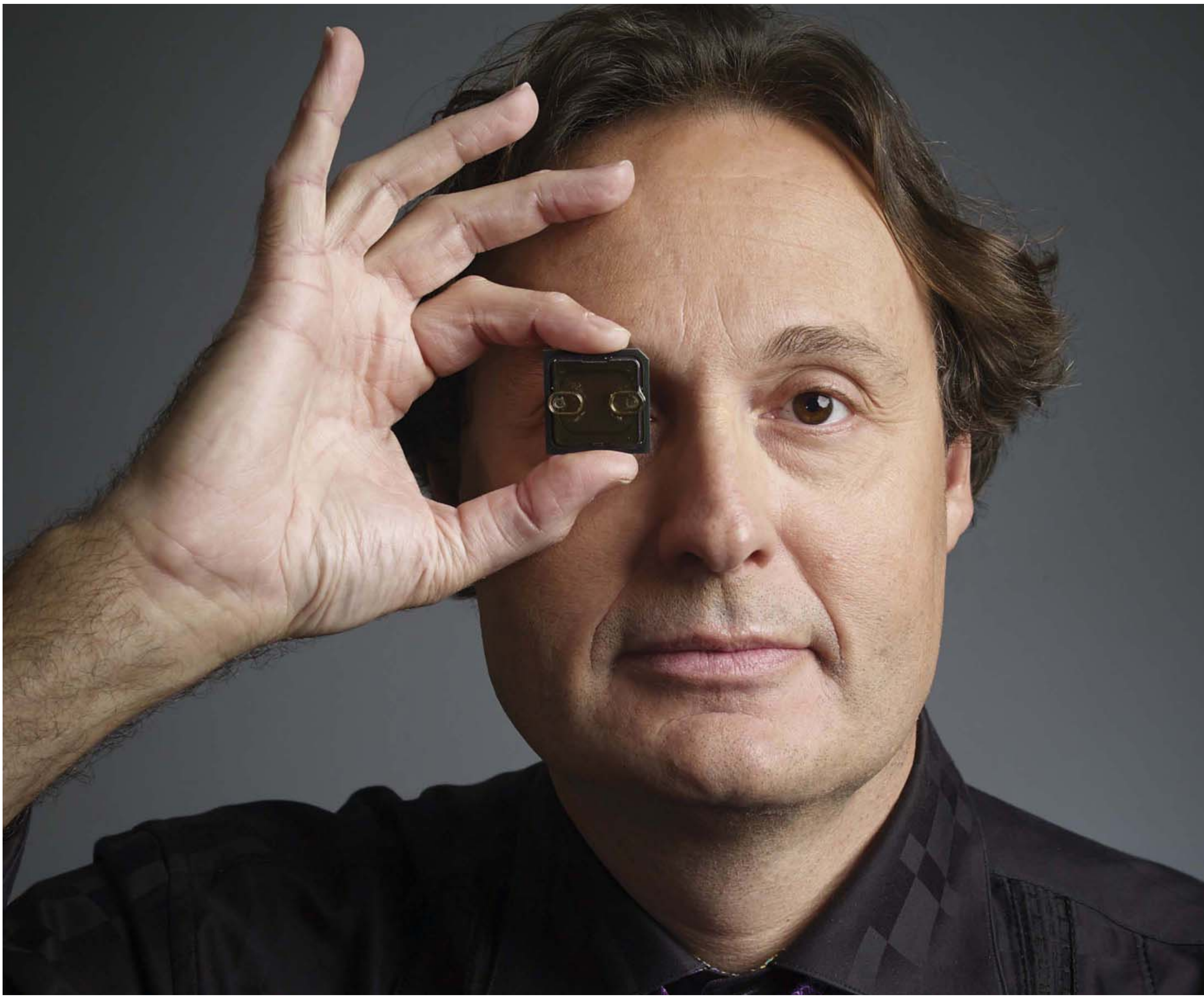

ON THE COVER **Illustration for *IEEE Spectrum* by Carl DeTorres**

PHOTOGRAPH BY David Yellen

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THE FUTURE OF COMPUTING High-performance computers play a role in all sorts of tasks these days, but people who work with the powerful machines are encountering roadblocks. IEEE's newest working group, Rebooting Computing, has set out to tackle these challenges.

SPOTLIGHT ON FEMALE ENGINEERS Despite their technical achievements, women represent only about 10 percent of engineers in the workplace. IEEE Women in Engineering is working hard to boost that percentage and raise awareness of women's contributions to technology.

IEEE MEDAL OF HONOR GOES TO JACOBS Life Fellow Irwin M. Jacobs, cofounder of Qualcomm, is this year's recipient of IEEE's highest award. He was recognized for "leadership and fundamental contributions to digital communications and wireless technology."

FROM LEFT: BOEING; THE ENERGY DETECTIVE; CELIA GORMAN

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BACK STORY_

Getting Personal With Gene Sequencing

Associate Editor Eliza Strickland, who has been a science and technology journalist for most of her career, can make a personal case for genetic heritability: Her father is a research scientist, and her mother is a writer.

Of course, the genetic basis of personality and behavior is still mysterious, and researchers continue to debate questions of nature versus nurture. In medical science, though, we're getting closer to real answers. Thanks to breathtaking advances in genetic sequencing, researchers are now finding genetic predispositions to such ailments as cancer and heart disease, and some physicians are offering genetic scans to patients to improve their treatments.

In this issue's "The Gene Machine and Me," Strickland focuses on a new sequencing machine that will soon enable researchers to decode an entire human genome–a sequence of 3 billion molecules–for about US $1000. To make the story personal, Strickland had her own DNA run through the machine and had doctors analyze the resulting data. She asked the doctors to reveal everything they found in her genome, no matter how alarming, and she decided to share that information with *IEEE Spectrum*'s readers.

That decision would affect her family: After all, she inherited her genetic material from her parents and shares it with her sister, niece, and nephew. Strickland describes the process of decoding her family's genome both in these pages and in a one-hour radio special, which will be available on the *Spectrum* website and air on U.S. public radio stations this spring.

In the photo above, Strickland sits between her intrepid and obliging parents, holding a patch awarded to her by the researchers on completion of the sequencing project. We thank the Strickland family for baring all in the name of both science and journalism. ■

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CHRISTOPHER THOMPSON

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Mark Anderson

In "Beyond the White Paper," Anderson looks at unconventional ways of presenting technical information [p. 21]. An *IEEE Spectrum* contributing editor, he came across the topic while researching new superconductivity experiments: Surprisingly, Anderson found the theory that best explained the results not in a paper but in a PowerPoint presentation. "I realized there's plenty of room for technical 'papers' that might never be found on actual paper," he says.

Joachim N. Burghartz

Burghartz, an IEEE Fellow, is a professor at the University of Stuttgart, in Germany, and directs the Institut für Mikroelektronik Stuttgart. He has devised a way of making silicon chips thin and flexible, like today's flexible organic semiconductors but with vastly more power ["You Can't Be Too Thin or Too Flexible," p. 34]. "The market potential and growth forecast in this area are enormous," he says.

David Kushner

Kushner, a *Spectrum* contributing editor, has always been fascinated with tricksters and their opponents, but his article on how Kaspersky Lab detected the Stuxnet worm [p. 46] is the first piece he's written about state-on-state cyberwar. "It was fascinating that one of the front lines of the cyberwar is an office park in the suburbs of Boston. The Kaspersky office seems so ordinary, yet the stakes are extraordinarily high," he says.

Lucas Laursen

The article "Robot to Human: 'Trust Me'" [p. 14] was a long time coming. Following Laursen's November 2010 *Spectrum* piece on "embodied cognition" in robots, a researcher told him about rescue robots' emerging empathy for humans. Laursen, who has been reporting from Europe for six years, finally wrote this story after the researchers had analyzed the results of a series of new experiments.

Steve Mann

A professor in the department of electrical and computer engineering at the University of Toronto and an IEEE Senior Member, Mann built his first computerized-vision system while he was still in high school. "People thought it was a crazy idea back in the '70s," says Mann. Since then he has constructed dozens of these systems and amassed more hours wearing them than anyone else, as he explains in "Vision 2.0" [p. 40].

Brian Stauffer

Stauffer's illustrations often touch on the darker side of life, and his graphic for "The Real Story of Stuxnet" [p. 46] is no exception. A self-described "significance junkie," he prefers illustrating articles where his work can have an impact. "It's hard, but it feels more real," he says. "My eyes are open. I guess I'd rather have my eyes open in this world." Stauffer lives in California with his wife and two sons.

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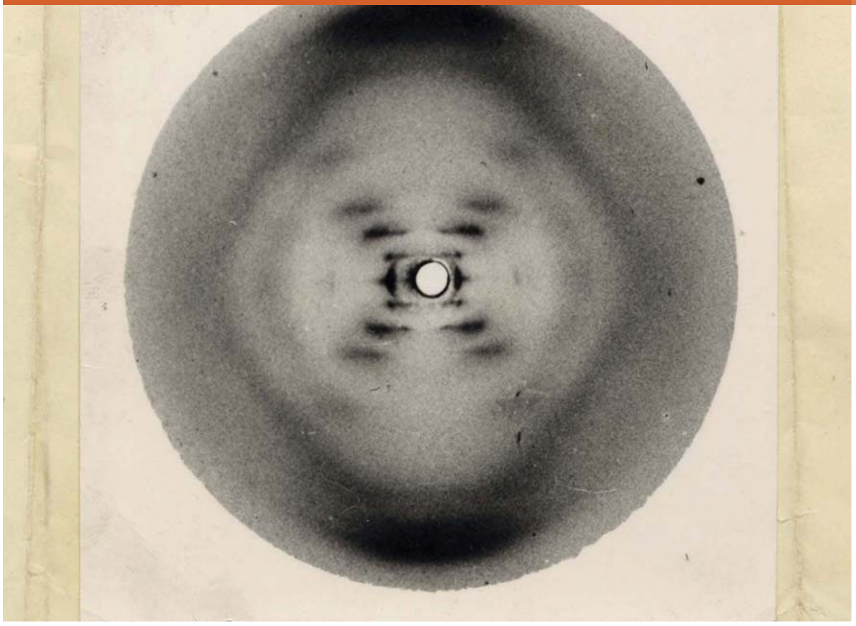

PHOTO 51: This historic X-ray diffraction image of DNA, taken in 1952 by Rosalind Franklin and Raymond Gosling, was obtained by stretching a fragile thread of crystalline DNA across a paper clip stuck in a cork, passing an X-ray beam through it for 100 hours, and capturing the results on photographic paper.

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Genome to Go

It's already possible to have your own genome sequenced. But personalized medicine based on sequencing still has a way to go

NEXT MONTH MARKS the 60th anniversary of the discovery of the double helix structure of DNA by James Watson and Francis Crick. To ordinary folks, the image (known as Photo 51) that confirmed the Watson-Crick model doesn't look like anything. But without this image—and without the brilliant work of X-ray crystallographer Rosalind Franklin—the Cambridge lads had a theory and a model but no actual proof that DNA was indeed "the molecule of life." It took Franklin's technical know-how and perseverance for that secret to be revealed. ● Biology is now one of many sciences that's almost completely dependent on technology: The technologies that allow us to view human biology at the molecular level have driven the genomic revolution. Automation, robotics, high-speed processors, and sophisticated computer programs have taken what was once the painstaking handwork of DNA identification, isolation, preparation, and sequencing and turned them into digital processes. The first sequencing of the human genome took 13 years and US $3 billion. Now machines the size of a multipurpose office printer will soon be able to do the same for sums of about $1000, and all in a day's time. ● But what will this mean on a human level? Eliza Strickland's article in this issue, "The Gene Machine and Me," is about her very personal experience with Ion Torrent's semiconductor-based genome-sequencing machines. These machines, which turn chemical signals into digital form, are the latest demonstration of the powerful electronic technologies driving all things genomic. In an echo of events 60 years ago, when several labs competed to discover the true nature of DNA, several companies are now racing to create genomic technology for widespread use. ● Why is this significant? After all, for $100 you can already send away a bit of spit to a direct-to-consumer DNA testing company like 23andMe. Their results will tell you if you're related to Genghis Khan, carry disease traits you could pass on to your children, or have an elevated risk of developing diabetes. These companies use a technology that examines the million points on the genome that vary among individuals.

But being able to predict, prevent, or treat disease based on the sequencing of your entire genome—which is made up of 3 billion components—is a far more complicated business. It's also more rewarding. The collection and analysis of large sets of individual genomes should eventually help researchers establish the root causes of complex diseases and allow them to create individualized treatment and even cures.

Patient-driven, personalized, "precision medicine" has significant hurdles to overcome, and not just technical ones. One of the most important is how to sequence millions, if not billions, of people to broaden our understanding of which genes correspond to which disease vulnerabilities, as well as other inherited characteristics. And while we're doing that, we'll need to develop more big-data software programs to sift through all the information from these genomes—a single human genome alone is about 4 gigabytes.

Other big challenges include training doctors to use genomic information in their practices, getting pharmaceutical companies to give up their blockbuster drug revenue model, and goading insurance companies into abandoning their rigid reliance on actuarial tables. And all this must happen as we simultaneously take on the inevitable genetic discrimination problems and myriad other ethical issues that will spring up.

As the former editor of a biotechnology journal, I have seen lots of breakthroughs, revolutions, and quantum leaps heralded as being on the brink of transforming our lives forever. But these transformations never occur overnight and take years, often decades, to reveal themselves.

That's the case with human genomics and its impact on medicine. Genetics has been poised to change medicine since Gregor Mendel tended his peas. In 10 years or so, after we've all had our genomes sequenced and are toting them around on our tricorders, the benefits for medicine of genome sequencing and its attendant technologies should become truly apparent—as will all the tics and bumps that make each of us uniquely human. —SUSAN HASSLER

NEWS

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NUMBER OF HOURS BOEING TESTED BATTERIES IN FLIGHT

A COMPLEX SYSTEM: Boeing's fuel-efficient 787 Dreamliner involved design input from many suppliers. The plane went to customers two years late.

BOEING

BOEING'S BATTERY BLUES

Despite fires in the 787's lithium-ion batteries, planes will become more dependent on electricity and batteries

IN JANUARY, regulators in Japan and the United States grounded the worldwide fleet of Boeing 787 Dreamliners after lithium-ion batteries caught fire in two of them—one in the air over Japan and the other on the ground in Boston. As *IEEE Spectrum* went to press, authorities were tracing the proximate cause of the Boston fire to a short-circuit in one of the batteries. The ultimate cause remained unclear.

What is clear, though, is that lithium-ion batteries in commercial airliners are probably here to stay. Airliners are going to keep electrifying previously mechanical systems like those used for braking and de-icing, because doing so makes the aircraft much lighter and more efficient, says Cosmin Laslau, an electrochemistry expert and technology analyst for Lux Research.

A heavy reliance on electrical systems, together with extensive use of ultralight carbon composites, is what cuts the 787's fuel consumption by 20 percent versus the competition's—its main selling point. (The batteries are mere backup to the six—count 'em, six—generators that supply the 787 with a whopping 1.5 megawatts, about five times as much as in any comparable airliner.) And lithium-ion batteries are likely to remain the technology of choice for new airliner

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designs, says Laslau. They're valuable not just for the great amount of energy they can store in comparatively little space and at a lighter weight but also for the big spike of current they can kick out. What's more, lithium-ion technology is getting better and safer by the year, while older battery technologies, like nickel metal hydride, are essentially standing still.

That said, figuring out what went wrong and how to fix it will be crucial to the future of the technology–and of Boeing. Damage to the batteries in Japan and Boston was extensive, suggesting that there were mishaps in the first two layers of the redundant safety system. The first layer contains two independent electronic control circuits, which manage the batteries' operation, keeping voltage within bounds and preventing overcharging. This control system is also supposed to prevent full discharging, which would keep a lithium-ion battery from ever being recharged again.

The second layer of protection involves the thermal sensors inside the battery itself, which are supposed to detect overheating and halt it by disconnecting the batteries. It was the third and final layer–shielding meant to contain a fire–that saved the day. Even so, some flammable electrolyte leaked from the batteries.

When lithium-ion batteries were introduced in mobile electronics, they gained infamy for incineration. The issue stems from a self-accelerating process called thermal runaway.

A lithium-ion battery typically has a carbon anode, a metal oxide cathode, and, sandwiched between them, an electrolyte consisting of a lithium salt dissolved in an

BURN OUT: Thermal runaway cooked this battery from an auxiliary power unit in a Japan Airlines 787.

organic liquid. When current flows into the battery, lithium ions move from the cathode through the electrolyte to the anode; when current flows out, they return to the cathode.

Too much voltage, too high a charge, too high an ambient temperature, or a combination of these things can trigger thermal runaway. According to the U.S. National Transportation Safety Board, it was heat, caused by an unexplained short-circuit in one cell, that started thermal runaway, which then cascaded through neighboring cells.

In one scenario, Laslau says, "as the temperature goes up, a protective layer on the surface of the anode breaks down," he says. Next, heat makes its way across to the electrolyte, breaking it down and releasing flammable gases like ethene and methane. That can cause pressure to build up in the cell. Then the heat begins to melt the separator, a polymer membrane that normally keeps the cathode and anode apart. If that happens, the cell can short-circuit, releasing much more heat. Finally, the cathode breaks down, releasing oxygen. Because the fire creates its own oxygen, it can't be put out easily and must therefore be contained.

The battery, made by Japan's GS Yuasa, was Boeing's choice for the 787's design in 2005, which Laslau says is unfortunate because its cathode was based on cobalt oxide. "The cobalt oxide chemistry that Boeing chose has a fantastic energy density, but it's not the safest. Lithium iron phosphate would be safer," he says. But the iron phosphate alternative wasn't well developed seven years ago.

Perhaps Boeing's reliance on relatively old technology reflects the many hiccups that slowed the development of the airliner, which went into service in 2011, about two years later than planned. "You could call it teething pains, but there was an awful lot of it, the worst in many decades," says Richard Aboulafia, an analyst with the Teal Group, an aerospace consultancy in Virginia.

Boeing has itself placed some of the blame for missed deadlines on its unprecedented decision to employ vendors around the world–not only to provide critical systems but in many cases to design them. "This arrangement is called working with 'risk-taking suppliers,' " says physicist Hans Weber, who runs Tecop International, a San Diego aviation consultancy. "Detailed design is up to the suppliers in many cases, who use their own money and get paid only when [the system is] delivered." But, he adds, Boeing underestimated how much management attention would have to be given just to keep suppliers up to speed.

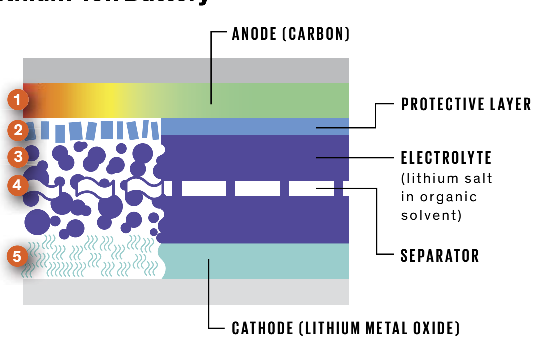
As the project stretched out, the suppliers felt the economic pressure. Reuters reported in January that whistle-blowers working for some of those companies had gone to the National Transportation Safety Board with allegations of cutting corners, including one case involving the battery chargers.

Boeing bet big on a daring concept and, despite the 787's production delays, won contract after contract from airlines, at least before the battery imbroglio. It could be that Boeing's example will save its competitors from teething pains of their own. Its archrival, Airbus, is developing a fuel-conserving alternative to the 787 called the A350. It, too, will use a lot of carbon composites–and a lot of electricity. And its design, too, relies on lithium-ion batteries. –PHILIP E. ROSS

U.S. NATIONAL TRANSPORTATION SAFETY BOARD/REUTERS

Thermal Runaway in a Lithium-Ion Battery

1. Heating starts.
2. Protective layer breaks down.
3. Electrolyte breaks down into flammable gases.
4. Separator melts, possibly causing a short circuit.
5. Cathode breaks down, generating oxygen.



NEW CAMERA CHIP CAPTURES ONLY WHAT IT NEEDS

Recording videos with compressed sensing could conserve phone power

BOTHERED BY HOW quickly recording video drains your smartphone battery? There's no app for that—but there may soon be a chip. Researchers at Sony and Stanford have constructed an imaging chip that incorporates a new technology called compressed (or compressive) sensing, to radically reduce battery drain by compressing video frames before they're digitized.

The problem with mobile video is this: Recording an image requires analog-to-digital conversions—lots of them. And each conversion consumes some energy. For a single conversion, it's not much, say a hundredth of a microjoule. But suppose your phone has an image sensor of 1080 by 1920 pixels. To capture one image, it must complete nearly 2.1 million conversions. So you need to multiply the energy of each A-to-D conversion by 2.1 million and then multiply the result by the number of video frames you capture—thousands for all but the shortest clips. A billion conversions here, a billion conversions there, and pretty soon you're talking about real battery drain.

But consider what happens next: The raw digital pixel values are compressed into a more compact format, perhaps a JPEG file for an individual image or an MPEG-4 file for video. Most images compress down by a factor of 15 without loss of significant detail, so few cameras do anything with the raw image data. Why then spend the time, trouble, and energy collecting all that information in the first place, if you're going to throw more than 90 percent of it away?

Up until recently, the answer has been that you can't figure out how to compress a signal until you have that signal. If you try to sample it too coarsely, you'd run afoul of the Nyquist-Shannon sampling theorem, which states that you can't capture a signal properly unless you sample it at least twice per cycle of the highest frequency component it contains. But it turns out that Harry Nyquist, who first formulated this idea in the context of telegraph transmissions—and, later, information-theory pioneer Claude Shannon—had missed something.

Perhaps the easiest way to understand their oversight is by recalling those old brain teasers: How can you use a balance scale to find one ball in a larger set that's slightly heavier (or lighter) than the others using the fewest possible weighings? Answer: Rather than weighing one ball at a time, you weigh selected groupings to infer which ball is the odd one.

Most images don't have just one pixel that's different from all the others. But it turns out that compressing images isn't all that much more challenging than finding that wonky ball. You merely pick random combinations of pixels and sum their intensities. Amazingly enough, with a sufficient number of such measurements (but far fewer than the number of pixels), you'll have enough data to reproduce the original image.

This astonishing result came out of work that Emmanuel Candès and David Donoho (both at Stanford), Justin Romberg (now at Georgia Tech), and Terence Tao (University of California, Los Angeles) began in 2004. Since then, scientists and engineers in many disciplines have been looking to apply compressed sensing to other problems—typically ones where the sensor arrays are difficult or expensive to fabricate. That's

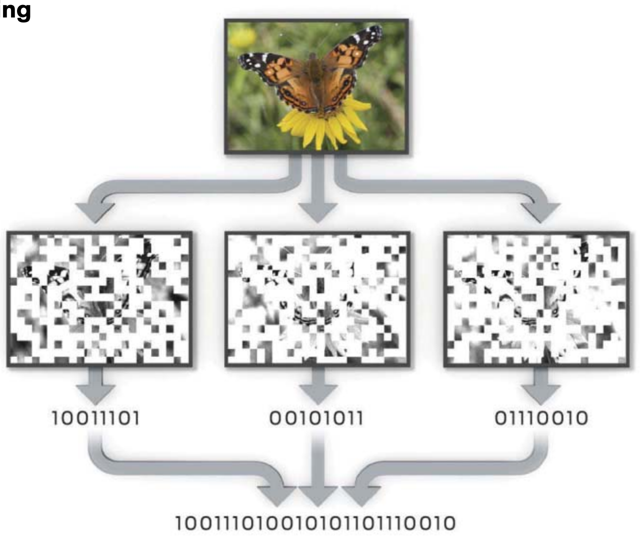
Compressed Sensing

1. An image can be sensed and compressed at the same time.

2. The trick is to sum the analog voltages of randomly chosen sets of pixels. You need many such sets, but far fewer than the number of pixels.

3. Only the sums are digitized.

4. These digitized values constitute the compressed image. Significant computation is needed to decompress it.



NEWS

ILLUSTRATIONS BY Emily Cooper

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why Austin, Texas-based InView Technology Corp., for example, is applying compressed sensing to shortwave infrared imagery. Visible-light imaging arrays don't have this problem. But as Yusuke Oike of Sony and Abbas El Gamal of Stanford realized in 2010 and 2011, when Oike was a visiting scholar at Stanford, the many A-to-D conversions they require consume more energy than smartphone designers would like.

At the time, El Gamal was involved in neurobiology research, examining the nerve cells of live, free-ranging mice by staining the cells with fluorescent dyes and attaching image sensors to the animals' brains. "We had a very small power budget on the head of a mouse," he says. And they knew that the power problem was more general. For example, power constraints limit the resolution of image sensors in endoscopic surgical instruments, El Gamal says: "Otherwise it burns your stomach." The most widespread opportunity for such power savings, though, is in our phones.

To explore how compressed sensing could help, Oike and El Gamal designed a custom CMOS chip with a 256- by 256-pixel image sensor. That chip also contains associated electronics that can sum random combinations of analog pixel values as it's making its A-to-D conversions. The digital output of this chip is thus already in compressed form. Depending on how it's configured, the chip can slash energy consumption by as much as a factor of 15.

The chip is not the first to perform random-pixel summing electronically, but it is the first to capture many different random combinations simultaneously, doing away with the need to take multiple images for each compressed frame. This is a significant accomplishment, according to other experts. "It's a clever implementation of the compressed-sensing idea," says Richard Baraniuk, a professor of electrical and computer engineering at Rice University, in Houston, and a cofounder of InView Technology.

But don't expect to see it in Apple's next iPhone. The biggest stumbling block is decompressing the image. The algorithms used for that require considerable computational horsepower—much more than would be available on a phone. "You'd have to do the reconstruction in the cloud," says El Gamal. Decompressing thousands of these videos every day would only exacerbate the demands our mobile lives are already placing on data centers and, in turn, on energy grids. Where will we find the power for all that, Siri? —DAVID SCHNEIDER

It takes only about 0.01 microjoule to digitize the output of a single pixel of a camera chip, but that adds up to about half a watt for HD video.

TECH FIRMS MINE MINSK'S MINDS

Belarus's somber, sprawling capital sprouts a flourishing computing scene

IN A QUIET LANE in Belarus's capital, across from playgrounds and tower-block apartments, sits an old textile factory with a courtyard mural of a smiling Vladimir Lenin. Upstairs is something unexpected—60 programmers and artificial-intelligence researchers implementing algorithms and building databases for a sprawling semantic-search platform.

This is what Ken Klapproth calls the "factory" for the Invention Machine, a 20-year-old software firm in Boston (recently acquired by Colorado-based IHS) that specializes in natural-language processing. Klapproth leads product marketing for Invention Machine and is a solid supporter of Minsk's IT scene.

MICHAEL DUMIAK

Over the last six years, software exports from Belarus have soared 2000 percent in light of a free economic development zone, with 80 percent of them going to the European Union and the United States. Alexander Martinkevich, deputy director of Minsk's 50-hectare Hi Tech Park, says that half the zone's participants are domestic firms and half were built from foreign investment. The growing technology industry in Belarus is becoming richly varied: A visitor can find code farms for established Western companies, bootstrapping developers working with start-up partners both foreign and domestic, and homegrown outfits like the successful gaming shop behind *Massive Assault*.

"The Belarusian IT industry stands on the shoulders of software outsourcing companies" that sprang up in the 1990s and 2000s, says Vitalina Turlo, head of marketing and business development for Applied Systems, an industrial automation firm in Minsk. "But the recent

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CODE ON, COMRADES! Artificial-intelligence experts program under the gaze of the father of Soviet communism. The headquarters of Invention Machine's R&D operation is just one of many IT outfits in Minsk.

trend is much more toward the emergence of highly successful product developers and companies." Marketing for these new companies remains a weak spot, she says, but they are getting better at it.

Often thought of in the West as a relic of the Cold War, Belarus actually owes some of its success to that conflict, says Jim Todhunter, who recently stepped down as Invention Machine's chief technology officer. "In the early days of artificial intelligence, natural-language processing was interesting because the United States and the Soviet Union wanted to spy on one another," he says. "So the hotbeds for this development for these technologies were in these two countries." Invention Machine was founded in Minsk in 1992 and took advantage of the local natural-language-processing expertise. The firm's core product is a custom semantic-search engine that can crawl through a vast variety of a client's internal documents and external information, including patents, scientific research papers, and standards data. It then serves up categorized lists of specialized information based on natural-language queries. Klapproth says the firm keeps its R&D operations in Minsk because its mostly Belarusian developers—even the recent graduates—are steeped in language algorithms.

What's happening now is broader than just local residents capitalizing on a niche expertise. When controversial Belarusian president Alexander Lukashenko—the country's leader since 1994—decided in 2005 to establish the Belarus Hi Tech Park on the outskirts of Minsk, the barriers to getting a spot there were low and the terms generous. Any software development company—whether physically quartered in the park or anywhere else in the country—is exempt from all taxes and customs duties, and employees get a fixed tax rate of 9 percent on personal income. "The whole territory of the country may be regarded as the park," Martinkevich says. "Legal conditions adopted for the park are valid within all of Belarus." Some 118 tech firms now call the place home, and new buildings are under construction.

That environment has helped to attract new business. Viber Media, for example, a fast-moving mobile app competitor to Skype, ballooned to 100 million users in two years from its base in Minsk, with its Israeli-born developers relying on Belarusian staff to keep its service running as it quickly scaled up.

When Todhunter arrived in Minsk a decade ago, it was a place where residents spent the winter shivering behind thin windowpanes. The city Todhunter is leaving is a curious place: On a single winter evening, you can find a leading poet chagrined about not being able to perform his songs in public and a Russian-speaking thrash band with a Japanese drummer in a squatter club. But the city is also now more vibrant, boisterous, confident.
—MICHAEL DUMIAK

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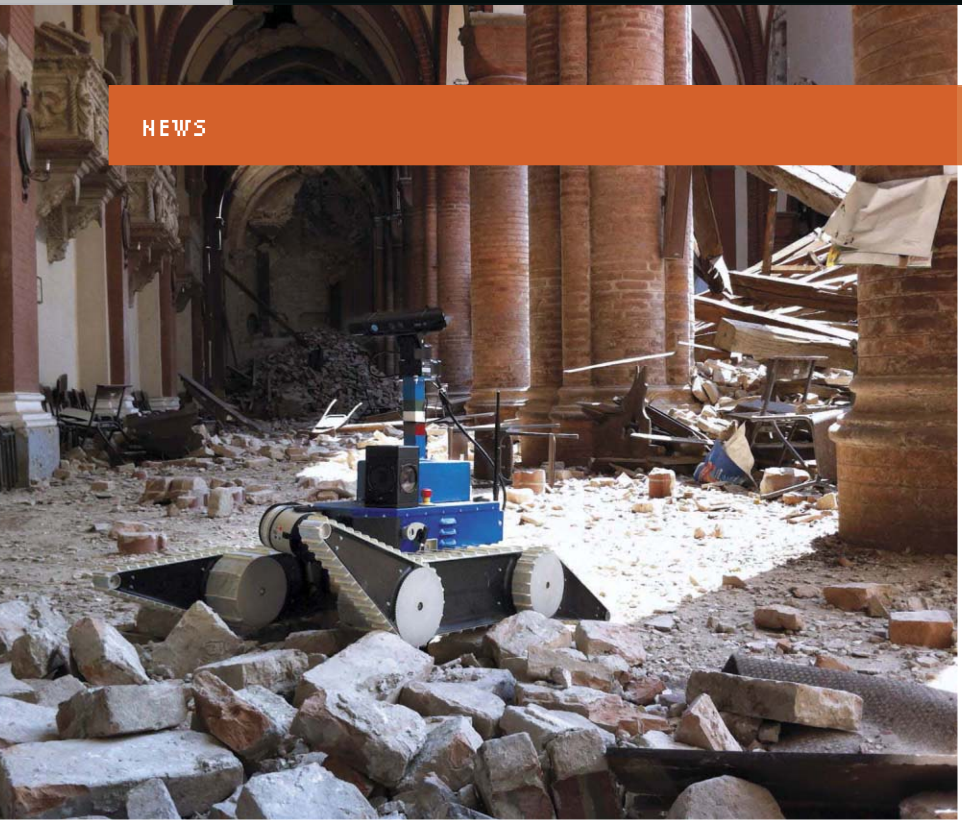

NEWS

SEARCH AND RESCUE: Researchers in Europe explored how well rescuers worked with robots in disaster situations. They found the relationships a bit strained.

ROBOT TO HUMAN: "TRUST ME"

Rescue robots must learn to respond to operator stress levels

IN A CRISIS CONTROL CENTER, several teams of firefighters in Montelibretti, Italy, used laptops to guide a robotic ground vehicle into a smoke-filled highway tunnel. Inside, overturned motorcycles, errant cars, and spilled pallets impeded the robot's progress. The rover, equipped with a video camera and autonomous navigation software, was capable of crawling through the wreckage unguided while humans monitored the video footage for accident victims. But most of the time the firefighters took manual control once the robot was a few meters into the tunnel.

Although the search was just an experiment, microphones recorded clear signs of stress during several tests of the scenario: The firefighter driving the rover spoke at a higher pitch, and members of some teams also interfered with one another's radio transmissions. And while the human drivers may have improved the robot's performance, they should have been more focused on the search for victims, says artificial-intelligence expert Geert-Jan Kruijff of the German Research Center for Artificial Intelligence, in Saarbrücken, who consulted on the experiment. The drivers were micromanaging their robots.

The same thing has already happened in the real world: After the Fukushima nuclear power station's meltdown in 2011, a human driver refused to use a ground robot's autonomous navigation and managed to get the rover tangled up in its own network cable. At a disaster scene with lives on the line, human rescuers need to learn to trust their robotic teammates or they'll have their own meltdowns, says Kruijff.

"We've done a lot of work on autonomy," Kruijff says, referring to robots' ability to navigate, "but if the user doesn't use it, what good is it?" He figures that rescue robots will need to better understand their human teammates and communicate in a more sophisticated way.

The first step is to gather data to help figure out how to predict when human robot wranglers are overwhelmed. That's not easy, Kruijff and his colleagues say, and the team is considering different ways a robot can measure stress and attention in its handler. Just as the robots build three-dimensional maps of the physical environments they explore, their software must also build real-time maps of the psychological bottlenecks their human partners face during a rescue mission. Certain things, such as voice-pitch changes, are easy to measure unobtrusively. But strapping cuffs on firefighters to measure their blood pressure or using saliva swabs to measure their cortisol levels would be more trouble than it's worth.

The next step is to have the robot decide what and how best to communicate. A driver straining to interpret video of a rubble field might be less likely to ignore an audible warning about a nearby victim than a pop-up message on the screen, Kruijff suggests. His team, part of an international consortium that focuses on improving human-robot cooperation in dynamic environments (NIFTi), is considering various configurations of alerts.

Robots also need to better communicate their own abilities and intentions, says rescue robot researcher Robin Murphy of Texas A&M University, in College Station. At a chemical train wreck where her team tested an autonomous helicopter, a rescuer found that the robot bounced too much to take photographs when it first reached an assigned waypoint. The pilot's attempts to compensate led to more bouncing. In their next iteration of the control software, she explains, they included an icon on the rescuer's screen indicating when the helicopter's autopilot was correcting for gusts of wind before settling into place.

Murphy says that one of the strengths of the NIFTi approach is that it has created a series of tests with working firefighters in Italy and Germany. "Too much of our work in robotics has been in the lab," she says. "Rescue robotics…doesn't lend itself to reductionism.… You've got to be in the field with the users, see the robot as a joint cognitive system, and then find out what the scientific problems are."
—LUCAS LAURSEN

PANAGOTIS PAPADAKIS

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Every day, more and more of the things we see and use every day start life as a prototype printed on a 3D printer. It's a technology that is changing the world in some amazing ways. / Designers and engineers are using it to print amazingly accurate prototypes before they go to production. / Manufacturers are using it to print amazingly durable end-use parts and dramatically increase production efficiencies. / Animators, educators, game developers and medical and dental professionals are all using it to transform the way they work. / 3D printing is the next industrial revolution. And Stratasys is here to lead it. / Welcome to a 3D World.

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PHOTOGRAPH BY Anna Gowthorpe/Press Association/AP Photo

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ANALOG DATA STORAGE

SUPPOSE YOU'VE GOT 300 years' worth of actual made-from-trees newspapers—some 750 million pages in all. How do you preserve all that pulp while providing access to a researcher who pops in to read, say, the 12 October 1823 edition of *The Times* of London?

The British Library's answer is the soon-to-be-completed Newspaper Storage Building in the village of Boston Spa, in West Yorkshire. The 64- by 24- by 24-meter space will be outfitted with robotic shelving capable of delivering any individual issue to librarians, relieving them of the need to search the overgrown storage locker. Temperature, humidity, light, and oxygen levels inside the airtight space will be closely monitored to keep the newsprint from degrading or catching fire. And to keep the room and its contents free of contaminants, papers will be delivered through air locks similar to the ones astronauts step through when they return from space walks.

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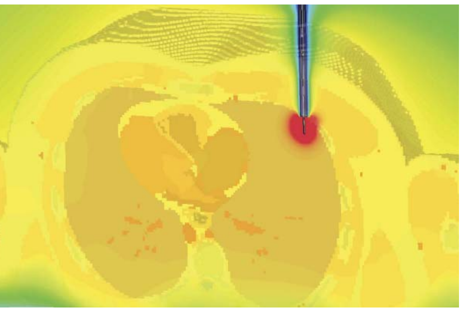

Simulation of cancer treatment by RF thermoablation

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RESOURCES

THE IEA ESTIMATES THAT BY 2050, SMART GRIDS COULD REDUCE ANNUAL CARBON EMISSIONS DUE TO ELECTRICITY GENERATION BY 20 GIGATONS.

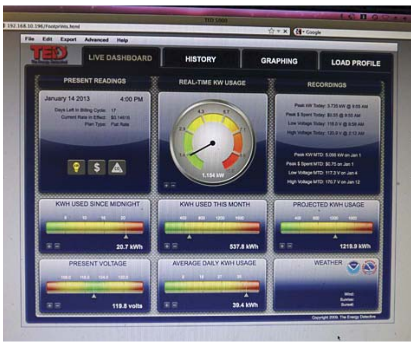
RESOURCES_HANDS ON

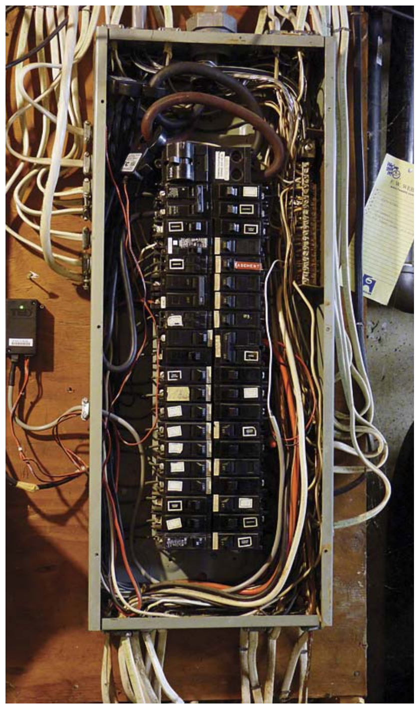
PARSING POWER

HOW A SMART METER KIT CHANGED MY ENERGY HABITS

When you hire a detective, sometimes you find out things you don't want to know. That's true of smart power meters just as much as it is for the traditional gumshoe and telephoto lens variety. • Our local utility is planning to install smart meters some time this year—perhaps—but how much of the information the utility will share with customers is still unclear. So I reckoned that having our own smart power unit could be a good investment, and certainly an intriguing project. When *IEEE Spectrum* got a residential TED 5000 Energy Detective unit for review, it all seemed very straightforward: Attach a monitoring unit to my home's electrical distribution board, see where the energy was going, take steps to reduce waste, and reap the financial rewards. • The first hitch I ran into was right at the beginning of the installation instructions, which start by telling you to open up your distribution board and attach voltage-sensor wires to two successive spare circuit-breaker positions. Our mid-'70s house ran out of spare breaker positions not long after construction and has since had two subpanels added. Although I do have a few spaces in the subpanel on the other side of my house, the kit also comes with two current-sensing-loop clamps that need to be placed around the main feed lines into the house. • As it turns out, this problem wasn't insurmountable: What the instructions actually mean is that you need to make contact with both the +120-volt and –120-V bus bars in the panel to get accurate readings. I sensibly let an electrician take care of that chore while he was here doing some other work, so it added perhaps US $15 to $30 to the cost of the smart meter kit, which was $240 for my version, the TED 5000-C. The C version comes with a dedicated display; you can also get a kit for $200 without a display from the makers, Energy Inc., based in Charleston, S.C. ▸

THE ENERGY DETECTIVE





POWER PLAY: Once you've installed the monitoring unit in your home's electricity distribution board [above], you can examine current and recorded energy use with either a Web browser [top left] or a dedicated display [left].

The sensors connect to a measuring and transmitting unit. This unit uses a power-line communication protocol to transmit data to a gateway, which plugs into a spare wall socket. The gateway, in turn, transmits wirelessly to the dedicated display, a tiny portable unit with a monochrome LCD and a mode button that displays current or cumulative power consumption in kilowatt-hours or dollars. This display has to be closer to the gateway than you'd think—within about 10 meters—for it to work.

Fortunately, the gateway also has an Ethernet port. I used the port to wire the gateway to my local area network. That's when the fun really began. An installation utility (available for Microsoft Windows and Apple's OS X) gave me the network address of the meter; directing a browser to that address served up a Web page with a real-time display of kilowatts, volts, dollars per hour (assuming you tell the software your electric rates), and so forth. Additional pages offer usage charts. The system stores recent measurements about every 2 seconds. It saves several months of older measurements with a minute-by-minute history.

It was great fun walking around with a tablet connected to my local network via Wi-Fi, turning off lights and watching the colorful little power consumption gauges go down. But it was also a little sobering to see just how much it cost to leave a pull-chain light burning in the far dark corner of the basement.

Worse yet, after the first kilowatt or so of savings, the easy pickings for reducing consumption stopped. If you work at home, your PC is going to be on all day. Figure a couple of hundred watts for that right there. If you have a digital video recorder to save your favorite shows, it's going to be on too. Routers, switches, hubs, laptop and tablet chargers, smoke detectors, cordless phones—they all consume power throughout the day.

Even when nominally off or in standby mode, many devices continue to consume a fair amount of electricity, costing the average U.S. home $100 per year according to the United States' Environmental Protection Agency. Unplugging these devices is a lifestyle change I'm not willing to make. Then there's the washer, dryer, refrigerator—the list goes on—the abandonment of which would mean even more radical lifestyle changes.

And in a house built during the late 20th century, there's even more power consumption from electrical equipment that would be difficult to unplug even if I wanted to: the motorized pump that sprays a mist of oil through the furnace burner, the motors that push air or water through the heating system, and in our case, even a motor that pumps wastewater uphill to the city sewer system. None of these is optional in a house designed for them. In total, it all adds up to a baseline of 10 to 15 kilowatt-hours every day.

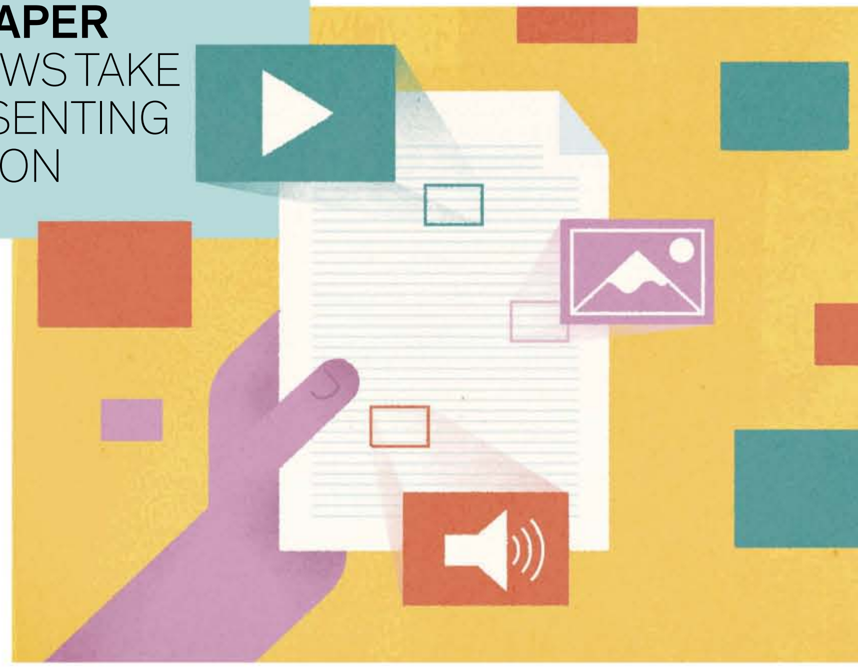
Should I be surprised that a household with a lot of electrical gadgets and appliances consumes a lot of electricity? Probably not. But the Energy Detective display right next to the dining room table makes it harder to just go on about my everyday business. Flicking the light switch down as I leave a room is becoming more of a habit, those LED bulbs in the hardware store are looking more attractive, and I may even figure out some way to control that light at the other end of the basement that involves neither climbing gear nor calling in an electrician. And ultimately (in addition to the actual savings in energy bills), that mindfulness may be the best thing. —**PAUL WALLICH**

PAUL WALLICH (3)

RESOURCES_AT WORK

BEYOND THE WHITE PAPER

VIDEOS AND SLIDESHOWS TAKE CENTER STAGE IN PRESENTING TECHNICAL INFORMATION



It sounds like a trick question, but it's not: Do white papers need to be either white or paper? Authors are preparing a small but growing number of technical documents today that are intended to be read on a tablet or smartphone screen. And some of these multicolored, multimedia presentations and PowerPoint-style slideshows are having as big an impact as that of any traditionally arranged document.

The growing popularity of these next-generation white papers can be gauged from the SlideShare website, which according to a spokesperson has 50 million unique visitors per month. Technology is the site's second most popular slideshow category, just behind business and management.

These new white papers often make use of video, audio, and interactive elements. The most sophisticated versions, such as a presentation by market intelligence firm International Data Corp. on the world of big data, are complete microwebsites with video and graphics to convey the message. (For the more traditionally minded, IDC also made a printable PDF of "The Digital Universe in 2012" available for download.)

Gordon Graham, a white-paper writer based in Thessalon, Ont., Canada (and author of the forthcoming book *White Papers for Dummies*) agrees that the IDC site does a good job of integrating video, audio, graphics, and interactive elements to create an effective nonwhite, nonpaper white paper. But it's a rare example, he warns, and most next-generation white papers show that the medium is still trying to find itself. "There are some major problems that afflict far too many of these documents," Graham says. "Too much hype, and not enough evidence [is presented]."

In particular, Graham points to many video white papers that rely heavily on poorly shot talking heads combined with generic stock video footage. "I'm afraid we're going to have to go through a phase like we did with clip art and stock photography while people get used to what really works and what doesn't," he says.

Perhaps surprisingly, the workhorse file format for many of these new-media white papers remains the familiar PDF, because it can act as a general-purpose digital container, says Jonathan Kantor, a white-paper writer based in Tequesta, Fla. "As PDF technology is advancing, we're starting to get requests for embedding short videos or online polls," says Kantor.

But despite the opportunities provided by multimedia technology, creators should know their limits, Kantor adds. According to Graham, a typical white-paper budget might be US $4000 to $8000, while professional video production can run upward of $1000 per minute. Fortune 500 companies may have the budget needed to make good-looking 10- or 15-minute videos to incorporate within white papers or as substitutes for them, he says, but fledgling companies should consider more modest approaches.

"There's a profound difference," Graham observes, "between what's possible technically and what's doable practically for most people and most companies." He says that companies shouldn't feel compelled to jump on the video bandwagon and suggests they consider audio and animation instead. But although these approaches are cheaper than professionally produced video, they still require some investment. "I've heard of executives who use text-to-speech converters to make MP3s out of documents," he says. "It's this terrible computer voice. What's wrong with getting some voice talent and getting someone to actually voice your six-page white paper?"

Kantor says professional voice actors can be hired for about $75 per hour via clearinghouse sites like Voice123.com. With such an actor working to a short script and free audio editing software such as Audacity, he says, "a writer or in-house marketing professional could add [good quality] narration to a PDF file without substantially increasing the development cost."

—MARK ANDERSON

ILLUSTRATION BY Jesse Lefkowitz

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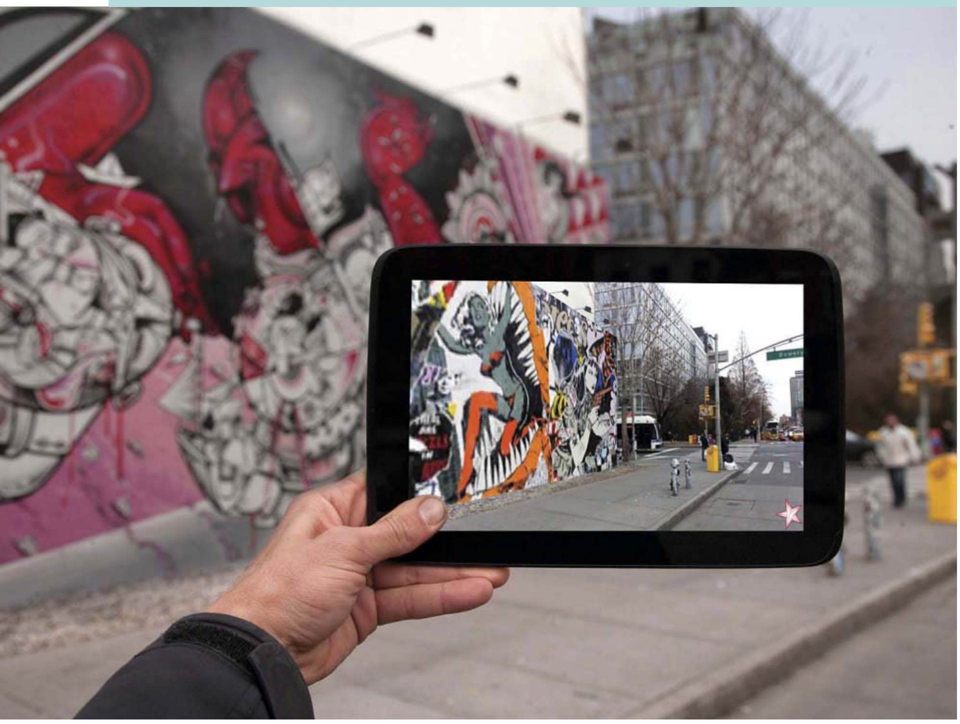
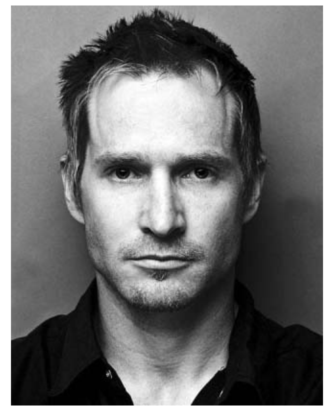
AUGMENTED REALITY FOR PUBLIC SPACES

BC "HEAVY" BIERMANN CREATES HIGH-TECH ART PROJECTS WITH A CIVIC MISSION





A PUBLIC ARTIST: BC" Heavy" Biermann uses augmented reality to transform public spaces—for example, replacing this old New York City mural with fresh art.

AUGMENTED REALITY (AR) HAS ALREADY PIQUED INTEREST IN the business, health, education, and entertainment communities. Now artists have begun harnessing the technology as a means of expression and social commentary. At the forefront of this burgeoning movement is BC "Heavy" Biermann. ● Biermann is a self-taught programmer and transmedia scholar with a foothold in both Los Angeles and St. Louis. His nickname reflects his penchant for "heavy" academic discussion. His art projects often involve overlaying interactive digital facades on public buildings and spaces and have attracted interest from public and technical audiences alike. ● This month, Biermann brings his insight to the IEEE panel "Omnipresent: When Virtual Meets Reality" at the South by Southwest Festival in Austin, Texas. The panel will discuss how AR is enhancing design, manufacturing, and medicine. ● "Augmented reality will become a more integrated part of our lives. The heavy hitters, like Apple, Microsoft, and Google, are recognizing this," Biermann says, referring to advances like Google's Project Glass and Microsoft's recent patent for AR glasses, both of

which will move the technology beyond its current home in smartphones. "The hardware needs to catch up to the software. Until AR can happen in glasses, it's not a seamless experience," says Biermann.

In 2005, Biermann founded The Heavy Projects (which last year brought aboard the digital media expert Ean Mering) to experiment with urban art and mobile AR technology. The following year, Biermann earned a doctorate in humanities and intermedia analysis from the University of Amsterdam. In 2011, he formed Re+Public with Jordan Seiler, founder of the PublicAdCampaign—which explores the negative effects of advertising in public spaces—to develop AR that reimagines those spaces.

"We're bombarded with commercial messaging whether we want to see it or not," says Biermann. In response, Re+Public creates interactive art on buildings in public spaces, creating digital murals that can be viewed via software running on a mobile device. "That way, not everyone has to see it," he says. "We're creating a platform to suggest how virtual overlay may one day undercut the need for physical advertising."

Re+Public's first big project was the "AR | AD Takeover" in July 2011, in which viewers held smartphones pointed at specific Times Square

RIGHT: MICHAEL BERGER

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MAGIC MURALS

DIGITAL DIMENSIONS: With augmented reality and mobile devices, muralists are no longer limited to two dimensions, as shown by these enhanced murals created for the Art Basel show, in Miami, last December.

OPPOSITE PAGE, LEFT, AND THIS PAGE: JORDAN SEILER (5)

billboards to reveal works of original urban-themed art. Following that, Re+Public produced projects that enabled viewers to see a decayed Norway mural restored to its original glory, three buildings in Los Angeles and New York City augmented with colorful designs, an in situ history of murals that once graced the Bowery (also in New York City), and reimagined versions of existing murals in Miami's Wynwood Art District. "We used AR to bring the murals to life by giving them a 3-D environment to 'live' in," Biermann says. "We also animated the murals and made them interactive."

Until now, most people have been able to see videos of these projects only on The Heavy Projects (http://www.theheavyprojects.com) and Re+Public (http://www.republiclab.com) sites. But this spring, Biermann and his team will make Android and iOS versions of the software available for public download, so that people can view them on their mobile devices.

The technical challenges are considerable. "It's difficult to do AR like this outdoors," says Biermann. "It's tricky getting the app to be consistent regardless of lighting conditions, day or night, and people walking in front of the mural."

Through The Heavy Projects, Biermann is now exploring applications of gaming principles, such as choice and narrative, in his AR designs, giving users options on how to "resurface" buildings so that people can see inside or what they might look like 20 years in the future.

In St. Louis, he's drawing on architectural tools in a prospective collaboration with Sung Ho Kim, an associate professor of architecture at Washington University, to digitally revitalize several of the city's buildings. "We would like to allow people to see how cities could look with better urban planning," Biermann says.

"Eventually, we'll have AR contact lenses and then—and this freaks everyone out—chip implants," he says, laughing. "In the not-too-distant future, humans will grow up with digital overlays onto the physical world as part of the natural experience. We're in the baby steps of what AR could eventually look like, and that's what we're excited about showing people." —SUSAN KARLIN

RESOURCES_APPWATCH

THE FINAL FRONTIER—ON YOUR PHONE

NASA brings its missions to the smallest screen

IN 1997, the website for NASA's Mars Pathfinder mission became an Internet sensation. But as the world has shifted from computers to smart gadgets, NASA has been increasingly using apps to reach the public. Some are tied to individual missions, while others educate users about scientific or engineering topics. Here are some notable examples:

Spacecraft 3D (iOS, free) is an augmented-reality app that lets users view 3-D models of 10 spacecraft, including the Curiosity rover, the Cassini orbiter, and the Hubble Space Telescope. First, you print out a paper target and place it on a surface. Then, via an iPhone or iPad camera, you can view the chosen spacecraft as it appears to hover above the target. Moving the phone or tablet around allows you to examine the craft from all angles.

With **ISSLive** (iOS, free), you can peer over the shoulders of astronauts or mission controllers. In addition to viewing detailed 3-D models of the International Space Station as it appears above Earth at any particular moment, you can also call up the crew's work schedule or visit a virtual mission control, which is constantly updated with live telemetry from the space station: For example, as of this writing, the temperature in the Destiny laboratory module was 21.68 °C, while the ISS's urine tank level was at 41 percent.

Designed for younger users, **Comet Quest** (iOS, free) is a game focused on the European Space Agency's Rosetta mission, which has a number of NASA instruments on board. Rosetta will orbit comet 67P/Churyumov-Gerasimenko in 2014 and deploy a small lander. Players must release the lander so that it touches down in a good spot. Then, as the Rosetta spacecraft orbits, users juggle observing the rotating comet, uploading data from the lander, relaying data back to Earth, and avoiding hazardous debris. —STEPHEN CASS

A version of this article appeared online in February.

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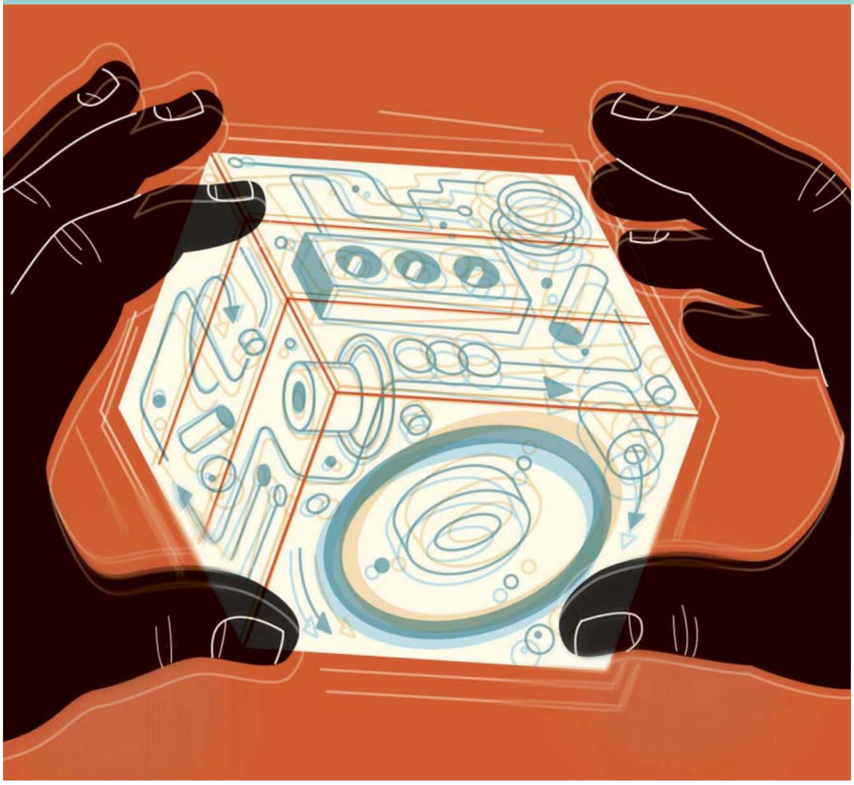


ANTIFRAGILE SYSTEMS

IN TITLING HIS NEW BOOK, Nassim Nicholas Taleb has coined a new word: "antifragile." I was not surprised that such a word did not previously exist, because, like most people, I had thought that the opposite of "fragile" was "robust." But Taleb argues that something that is robust merely tolerates adverse or unexpected conditions, whereas something that is antifragile thrives–its performance actually improves. He uses the example of a mailed package labeled "Fragile, do not shake." The opposite would say, "Antifragile, please shake." • Taleb's book mostly considers the notions of fragility and antifragility in biological, medical, economic, and political systems. Do we have any electronic systems that are antifragile? • Certainly, we engineers have done a superb job in designing robust systems that despite their burgeoning complexity have much longer life spans. The Internet is a leading example, having survived mostly intact for about three decades now (in the face of periodic predictions of its imminent collapse), with its robust flow control, alternative routing, and error control. • Evolution improves biological systems through survival of the fittest. Is there a similar improvement in the performance of electronic systems? Perhaps. But I don't think this is the same as the idea of designing a system that will actually work better when it experiences unexpected or random conditions. • There are, of course, power supplies that harvest energy from random vibrations, but perhaps that is too trivial an example. The closest examples I can find of antifragility in an engineered system involve multipath phenomena. • For the first half of the last century, multipath phenomena were harmful. In radio frequency transmission they caused signal fading as different paths became variously additive or destructive. In wire-line transmission there were similar effects due to the nonuniform delay of signal frequency components, resulting in intersymbol interference and degraded speeds. • These multipath impairments were eventually alleviated through diversity and adaptive signal processing. Still, I think of these adaptive systems as robust, rather than truly antifragile. Perhaps, though, we crossed the line to antifragile with the advent of multiple-input/multiple-output (MIMO) systems, in which we deliberately send multiple copies of the signal from different antennas, hoping there will be multipath phenomena that with processing can be used to enhance system performance. MIMO is now commonly used in IEEE 802.11n (Wi-Fi), and elsewhere.

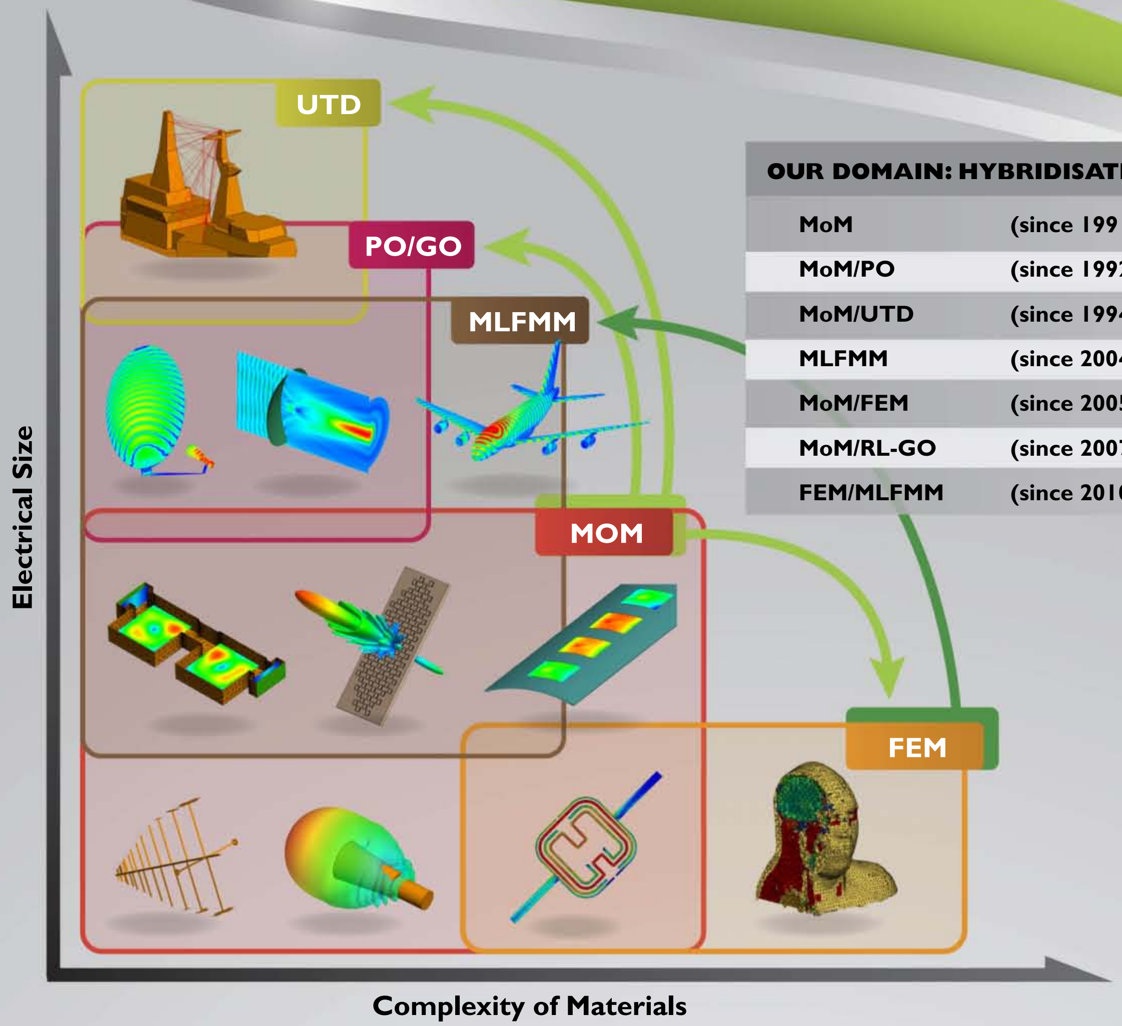
What I find fascinating now is the application of similar techniques in the new field of computational photography. In any scene, light arriving at our eyes or on a camera lens has come from multiple reflections, refractions, absorptions, and so forth. An ordinary camera captures an instantaneous superposition of all these arriving rays but loses any information about the directionality of rays, relative time delays, and individual amplitudes.

The first camera to record more of this information, the Lytro, is now a commercial product. Using a multifaceted lens and taking advantage of the ever-growing sensor capacity, the Lytro captures the directionality of light rays as they arrive. I am reminded of the early work in computer graphics that created lifelike representations using ray tracing, in which light rays–with all their reflections and refractions–are traced from a source to a viewer and computed to produce the image. With the Lytro we have the inverse problem: Given the rays, can we compute the scene? The Lytro software does exactly that and permits the user to choose a focus or move the perspective subsequent to image capture.

Recent experimental work at MIT carries this much further. Using a femtosecond laser to send extremely short pulses of light and repeating many times to gather enough signal strength, the system records times of arrival and relative amplitudes. The amazing claim is that it's possible to see around corners with this technology. Some of the arriving light pulses will be reflected from surfaces that aren't within the direct view of the detector. The more bounces, the better. Multipath is good; bring it on!

I invite the reader to think of other systems that might thrive under unexpected or adverse conditions. It's a thought-provoking challenge. ■

ILLUSTRATION BY Harry Campbell



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THE GENE MACHINE AND ME

This chip-based genome sequencer is cheap, fast, and poised to revolutionize medicine

BY ELIZA STRICKLAND

IT'S A FRESH APRIL MORNING IN 2012 WHEN I HEAD TO CONNECTICUT TO SEE A MAN ABOUT A GENOME. NOT JUST ANY GENOME, BUT MY OWN.

I want to learn my own biological secrets. I want to get a look at the unique DNA sequence that defines my physical quirks, characteristics, and traits, including my nearsighted blue eyes, my freckles, my type O-positive blood, and possibly some lurking predisposition to disease that will kill me in the end. So I'm not going to see just any man, but the mad scientist of genomics himself, the arrogant upstart of biotechnology, an inventor and entrepreneur who has upended the business of genetic sequencing once before—and now appears to be doing it again.

Jonathan Rothberg, founder and CEO of the company Ion Torrent, believes his cheap and fast sequencing machines will revolutionize medical practice within the decade. Indeed, he says, the revolution has already begun. In some hospitals, cancer patients can already have part of their genomes checked before their physicians decide on treatment. Newborns with life-threatening problems can have their genomes scanned to give doctors insight into what's wrong—hopefully, before it's too late.

Soon, Rothberg says, everybody will be sequenced—probably as infants—and will be able to make diet, lifestyle, and medical choices based on specific information, rather than on hunches about vulnerabilities. Knowledge of a person's genome will allow specialists to customize medical treatments and drugs for that patient, to maximize effectiveness while minimizing side effects. A routine checkup could start with the doctor checking for "updates" to a patient's genomic file; if medical research has turned up new data about the patient's particular set of genes, the doctor would get an alert. "Our goal," Rothberg declares, "is to really transform medicine."

To decode the first human genome, a milestone completed 10 years ago, armies of researchers labored for more than a decade and spent more than US $3 billion. Working with Rothberg's newest machine, a technician will soon be able to decipher a human genome in a few hours, and at the bargain-basement price of $1000.

My personal quest for genetic enlightenment begins with a visit to Ion Torrent's black glass headquarters in a Guilford, Conn., office park. Ion Torrent isn't really Rothberg's baby anymore—the company was bought by biotech giant Life Technologies Corp. in 2010 for $725 million—but he still strides through the facility with a proprietary air. He beams as we tour labs where biochemists and electrical engineers work side by side. The windows, pressed into service as extra whiteboards, are covered with scribbled sketches of molecular diagrams and circuit diagrams alike.

Several other companies are also racing toward the $1000-genome goal. But Rothberg was the first to tap into the accumulated expertise of the computer industry with a method he calls "semiconductor sequencing." Inspired by the cover of a computer magazine in a hospital waiting room, he figured out how to use an integrated circuit to record how a DNA molecule is built out of chemical components, and how to turn that chemical information into a digital readout.

Rothberg's newest product is a sleek machine called the Ion Proton System, which is just a little bigger than a fancy office printer. With just three disposable chips and a few hours of time, that machine can make sense of the genome of a human being, identifying each of the 3 billion molecules that make up a person's DNA. Ion Torrent's current top-of-the-line production chip isn't much by semiconductor-industry standards—it's got a measly 400 million transistors. But by tapping into the existing supply chain for microchip manufacturing, Rothberg has already improved his chips nearly a thousandfold, and he's not finished. Ion Torrent plans to ride Moore's Law as far as it will go.

Rothberg wants to be very clear about what all this means to medicine. "Look at the things that have added to life expectancy," he says during our first meeting. "It's clean water—that was the single biggest health improvement. Next came the antibiotics, next probably imaging, whether it's X-ray or MRI or CAT scan." He flashes a cocky smile. "I do believe that genome sequencing will have as profound an effect on medicine as clean water, antibiotics, and imaging."

I've come to Connecticut to learn about this hot new machine that might, in the words of one of the company's taglines, provide "sequencing for all." But I don't just want to hear about how it works; I want to try it out for myself. I know that having my genome sequenced will probably reveal something unusual about my genetic makeup. Quite possibly, that something will be disconcerting.

MAN AND MACHINE: Jonathan Rothberg says his genome scanner will revolutionize medicine.

"We are here," said U.S. president Bill Clinton, standing in the White House in June 2000, "to celebrate the completion of the first survey of the entire human genome. Without a doubt, this is the most important, most wondrous map ever produced by humankind." The map showed the placement of the 3 billion "letters" that spell out the human genome—all the genetic material contained in *Homo sapiens*.

Forgotten the genetics you learned in high school biology? Here's a refresher. Every cell in your body contains deoxyribonucleic acid, or DNA. That DNA is built from four molecules called nucleotides and identified by the letters A, G, C, and T, which stand for adenine, guanine, cytosine, and thymine. Think of DNA as a pair of chains, each shaped into a helix. The nucleotides are the links in the chain, and in DNA they pair up: One half of each pair is attached to one helix; the other half is attached to the other one. A always pairs with T, G always with C.

Genes are specific groups of letters on the long DNA chain. Each gene encodes the instructions for producing one of tens of thousands of proteins that conduct the business of life within our bodies. They include the hemoglobin that carries oxygen, the antibodies that fight infections, and the enzymes that permit the digestion of food, the contraction of muscles, and countless processes in the brain. By defining which proteins are produced and whether they're normal or irregular, the genome exerts enormous control over how we look, how we feel, and how we act—not to mention how and when we get sick.

Understanding the genome has long been a fundamental goal, and the federally funded Human Genome Project (along with a private company, Celera Genomics) completed a "rough draft" in June of 2000 and a final version three years later. The researchers analyzed genetic material from a handful of people to arrive at the sequence of letters that defines a typical human being. Every person's genome differs from that reference genome at a relatively small number of places in the long sequence of letters, but those tiny differences are enough to make us individuals.

Since the Human Genome Project launched in 1990, sequencing technology has advanced at a breathtaking pace, which genetic researchers speak about with a mix of awe and bitterness. "For my Ph.D., I spent six years and I sequenced 9000 letters," Rothberg says. He looks me in the eye and says it again, in a pained voice. "Six years. For 9000 letters." Rothberg was a Ph.D. student in the

PHOTOGRAPHS, PREVIOUS PAGES AND THIS PAGE, BY David Yellen

HOW AN ION TORRENT CHIP SEQUENCES A GENOME

To determine the unique sequence of DNA that defines an individual, doctors draw a vial of the patient's blood and extract the DNA molecules. They dice those long DNA molecules into many small pieces and load the fragments onto an Ion Torrent chip. Here's how the chip's sequencing technology works.

late 1980s, when the state-of-the-art method required researchers to laboriously analyze one DNA fragment at a time. In the 2000s lab techs rejoiced over the introduction of "massively parallel" machines able to analyze many fragments of DNA at once.

The first of those machines emerged from Rothberg's prior company, 454 Life Sciences. With a showman's flourish, Rothberg proved that machine's utility in 2007 by sequencing the entire genome of James Watson, one of the genetic pioneers who discovered the double-helix shape of DNA in 1953. The effort that Rothberg dubbed "Project Jim" took two months and was hailed as a breakthrough, for Watson's was the first individual genome to be sequenced, and it revealed the extent to which each unique human varies from the average. Watson, who has never been described as shy, promptly put his genome on the Internet.

As the technology made genetic scans faster and cheaper, doctors found ways to use them. Physicians have begun ordering scans for patients on diagnostic odysseys—chronically sick patients who have gone in for test after test without finding the cause of their illnesses. Cancer hospitals have started sequencing both their patients' regular genomes and the mutated versions found in tumors; this allows doctors to study genetic differences that encourage a tumor's growth and lets them look for drug targets. And massive research efforts are under way around the world. By sequencing thousands of people with autism, diabetes, or any other number of complex conditions, researchers hope to identify the specific genetic variations that are common within these groups.

Last March, a study from the insurance company UnitedHealth Group predicted that spending on genetic tests will skyrocket from about $5 billion in 2010 to between $15 billion and $25 billion in 2021. That market includes not only medical-grade scans, which a physician orders and interprets for a patient, but also tests that are sold directly to consumers by companies such as 23andMe, in Mountain View, Calif. These companies market their tests to the curious and the health-conscious and offer a very limited set of genetic results, most of which are interesting but not medically significant. Customers learn about genealogy, a few risk factors of questionable importance, and oddities like whether they're able to smell asparagus in their own urine.

I tell Rothberg that I want medically relevant results, and he puts me in touch with the pioneering Human Genome Sequencing Center at Baylor College of Medicine, in Houston, which collaborated on the Watson project. Baylor's researchers are working with Ion Torrent to validate its new Proton sequencing machine, and they agree to give me early access to the technology and to run my DNA through one of their Proton machines. I would be Baylor's first merely curious patient, but surely not its last.

Post your comments online at http://spectrum.ieee.org/genome0313

In late August, I find myself cozily ensconced in a Baylor conference room with the geneticist James Lupski, a professor in the medical school. The silver-haired physician had the task of telling James Watson his genome results in 2007. "I had to be the one to say, 'Well, Jim, we don't know what the hell your DNA means, because you're the first one to be sequenced,' " Lupski says with a crackling laugh.

Since then, Baylor researchers have been pushing to make genome scans useful. "There was the question, could we find things that were important for medical management?" Lupski says. "Was the signal above the noise?" The noise, he explains, is the thousands of genetic variants found in each individual, because "everybody truly is unique." In 2011, Lupski and his colleagues answered that question with 14-year-old twins who suffered from a palsy-like movement disorder. Whole-genome sequencing revealed not only the genetic mutation responsible, it also suggested a new drug regimen that worked remarkably well to control the twins' symptoms.

But the twins are still the exception. Baylor opened a commercial lab in October 2011 to provide sequencing services for doctors grappling with tough cases—patients who are on "medical mystery tours," as Lupski puts it. The lab has a 30 percent diagnostic success rate, which means doctors can pinpoint, in almost one-third of the cases, the mutations in a patient's DNA that are causing

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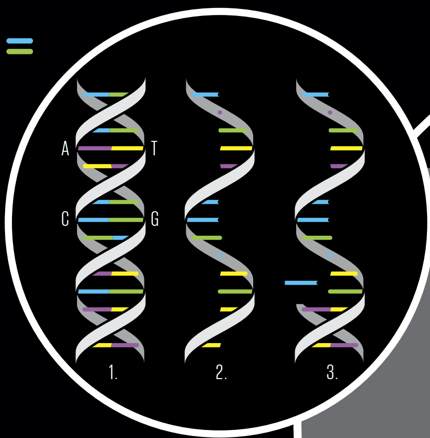

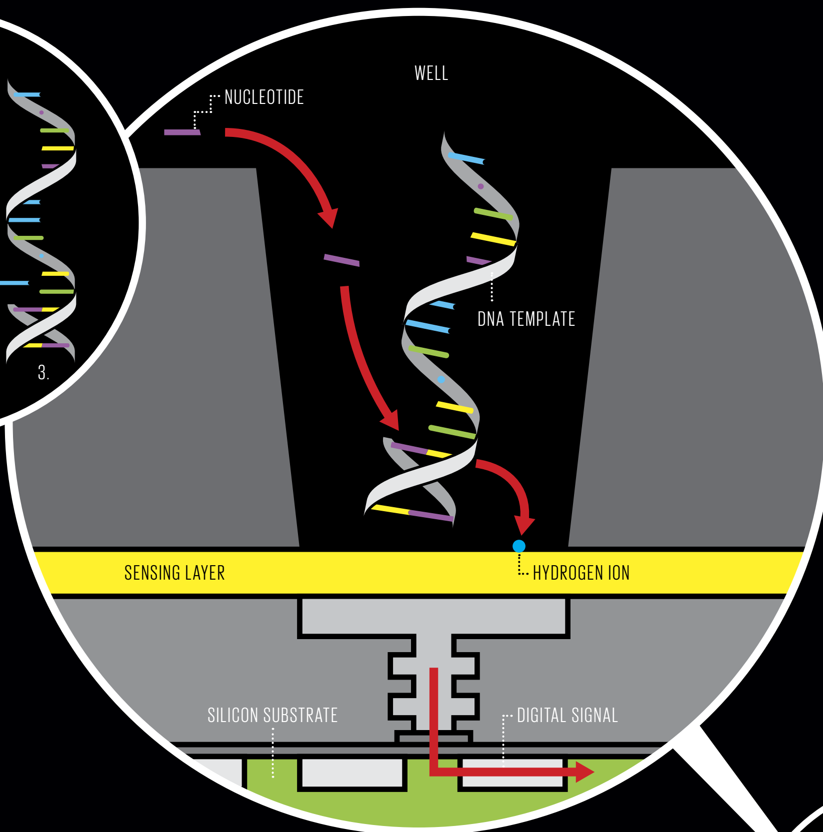

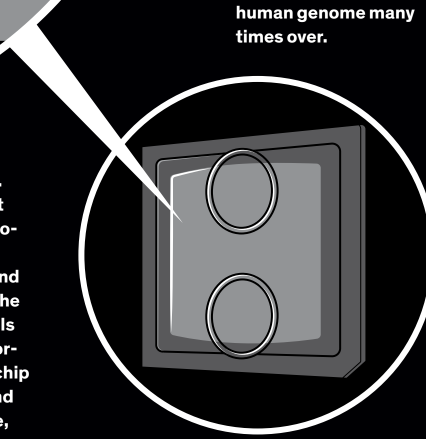

THE DNA

1. DNA looks like a twisted ladder. Each rung consists of two linked molecules called nucleotides, which always pair up in the same way: Adenine and thymine (A and T) always connect, as do cytosine and guanine (C and G).

2. To sequence a person's DNA, the ladder is first split down the middle to create a single-sided "template."

3. On the chip, sensors record the addition of each nucleotide to the template as the double-stranded molecule is rebuilt.

THE CHIP

Ion Torrent's current top-of-the-line chip, which has fluidic controls on the top and electronics below, contains 165 million minuscule wells. The digital signals from all those wells are combined and analyzed to spell out the sequence of letters that make up the DNA molecule. It takes three of these disposable chips to sequence one person's entire genome. With the company's forthcoming 660-million-well version, researchers will be able to use just one chip to sequence a human genome many times over.

THE SENSOR

A new nucleotide washes over all the tiny wells on the chip every few seconds. Each of the chip's wells holds a single-stranded DNA template. When a nucleotide is added to the growing DNA strand, the process releases a hydrogen ion, which changes the pH of the liquid in the well. The sensor at the bottom of the well reacts to that change in pH with a change in current through its transistor, and that digital signal is sent to the chip's electronics.

In the Ion Torrent machine, the nucleotide A first washes over all the wells, and the chip registers the signal from the wells where that A is incorporated. Then the chip is washed clean, and the next nucleotide, a G, floods across.

symptoms. That rate may seem pretty low. But doctors consider it a remarkable achievement, given the sprawling complexity of any human's DNA and how little is now conclusively known about how our genes function. As Lupski puts it, "in this branch of medicine, we admit our ignorance a lot more."

In the Baylor conference room, Lupski explains what his team will do for me: They will sequence only my exome, the portions of the genome that contain genes. While the 30-million-letter exome makes up just 1 percent of the genome, changes to those portions account for the vast majority of genetic diseases. The rest of the letters that make up the genome, historically dismissed as "junk DNA," play some role in human health, but the details aren't yet clear. Baylor's lab currently specializes in exome scans but may eventually switch to whole genome scans once medical understanding advances.

As we go over consent forms, Lupski tells me about all the terrible, horrible things this process could reveal about me. I could find out that I have genetic mutations that put me at high risk of developing a deadly disease like Parkinson's or cancer. Anything I learn, Lupski intones gravely, will have implications not just for me but also for my immediate family: my parents, my sister, and her children. I might also find out that I'm a carrier of some recessive genetic ailment, meaning that if my husband and I choose to have children and he's a carrier too, our kids could end up with that disorder. If there's bad news, do I want to know it?

I do. I've already talked the project over with my family. My parents worried at first that I'd discover something that would be hard to live with, but they ultimately gave their blessing. My sister was fine with it, too. "I'm not afraid of information," she said. So I tell Lupski not to hold anything back. I hope I'll get early warnings about problems I may encounter later in life and suggestions on screening regimens or lifestyle changes that can protect me.

I'm a trailblazer: Almost everyone tested at Baylor before me had one or more known serious diseases. I do not—as far

ILLUSTRATION BY James Provost

THE COMPETITION

Other biotech companies and start-ups are also striving to dominate the genome-sequencing market.

ILLUMINA: HISEQ 2500
Illumina's expensive but reliable machines are the market leaders and can be found in hospitals and labs worldwide. The company is focused on speeding up whole-genome sequencing.

PACIFIC BIOSCIENCES: PACBIORS
This machine, released in 2011, can sequence a human genome using only a single molecule of DNA. The technique provides highly accurate results.

COMPLETE GENOMICS
Complete Genomics doesn't sell its machines to researchers. Instead it offers them in-house genome sequencing and analysis packages.

OXFORD NANOPORE: GRIDION
This start-up hasn't released a commercial machine yet, but there's considerable excitement about its single-molecule sequencing technology.

CLOCKWISE FROM TOP LEFT: ILLUMINA; PACIFIC BIOSCIENCES; OXFORD NANOPORE; COMPLETE GENOMICS

as I know. But "what you find is that a lot of us have more susceptibilities to disease than anyone suspected," Lupski tells me. "Many of us are walking around with all kinds of things." As sequencing keeps getting cheaper, it will eventually become standard practice to screen healthy individuals for their vulnerabilities, Lupski believes. Just as physicians today take family medical histories from their new patients, they may soon order exome scans as well.

Lupski agrees to give me everything judged medically relevant, but no more: "We're not going to tell you what your genes say about the color of your hair or your eyes." No problem. I already know what color they are. I sign the consent forms and stick out my arm to let a doctor draw my blood.

Jonathan Rothberg is big on epiphanies. Right now, in a meeting room at Ion Torrent, he's telling me about the biggest one of his life, which occurred in a hospital waiting room on 2 July 1999.

Rothberg was then the CEO of a drug discovery company he had founded to trawl through the genetic data being produced by the Human Genome Project. But then, "on July 2 my son Noah was born," Rothberg says, "and he was having difficulty breathing. No matter how interested I was in this map that bound us all as humans, I really only cared about *his* genome." Understanding the genome in the abstract was all well and good, but a scan of Noah's personal genome could help doctors understand what was wrong–and possibly help them fix it.

While Rothberg paced in the waiting room, his gaze fell on the cover of a computer magazine, *InfoWorld*. It trumpeted the release of the Pentium III chip, which incorporated 9.5 million transistors. The drive to miniaturize semiconductors had produced the personal computer revolution, Rothberg thought, so maybe shrinking down sequencing technology could usher in a personal genetics revolution.

Noah's breathing problems passed quickly, and the parents took home their burbling infant. But Rothberg's revelation obsessed him, and he spent his two-week paternity leave roughing out the idea for a new sequencing machine. "I got in trouble for it," he said with a laugh. Those sketches led him to found his next company, 454 Life Sciences, which in 2005 introduced the world's first next-generation sequencing machine.

To understand how it worked, recall the DNA molecule. It looks like a twisting ladder, with rungs formed by pairs of As and Ts and pairs of Cs and Gs. This structure is fundamental to the mechanism by which DNA copies itself every time a cell divides. To reproduce itself, the double-stranded helix "unzips" down the middle, making each single strand a template; each A attracts a new T, each C latches onto a G, and so on, until there are two complete twisted ladders instead of one.

Next-gen machines typically rely on a method called sequencing by synthesis, in which a DNA molecule is broken up into many pieces of single-stranded templates. These templates are placed in thousands or millions of minuscule wells on a substrate inside the machine. Then the series of four nucleotides wash over the wells, one at a time, while the machine records which templates add the A, then the G, and so on, through millions of washes. In Rothberg's process, a firefly enzyme was attached to each nucleotide and produced a flash of light when it was added to the template. A camera inside his 454 Life Sciences machine took a photo with each wash to record the flashes.

While competitors scrambled to catch up, Rothberg promoted his machine with flair. He sequenced | CONTINUED ON PAGE 52

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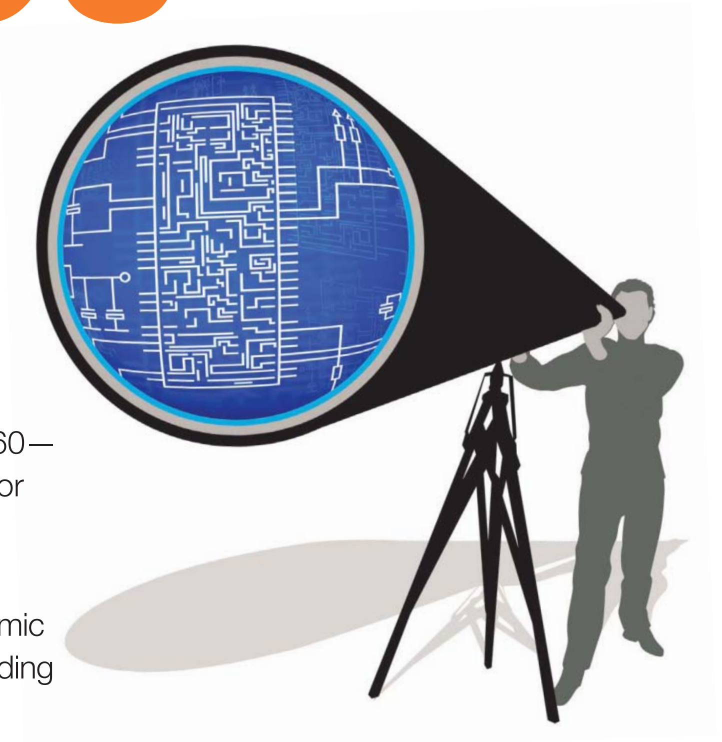

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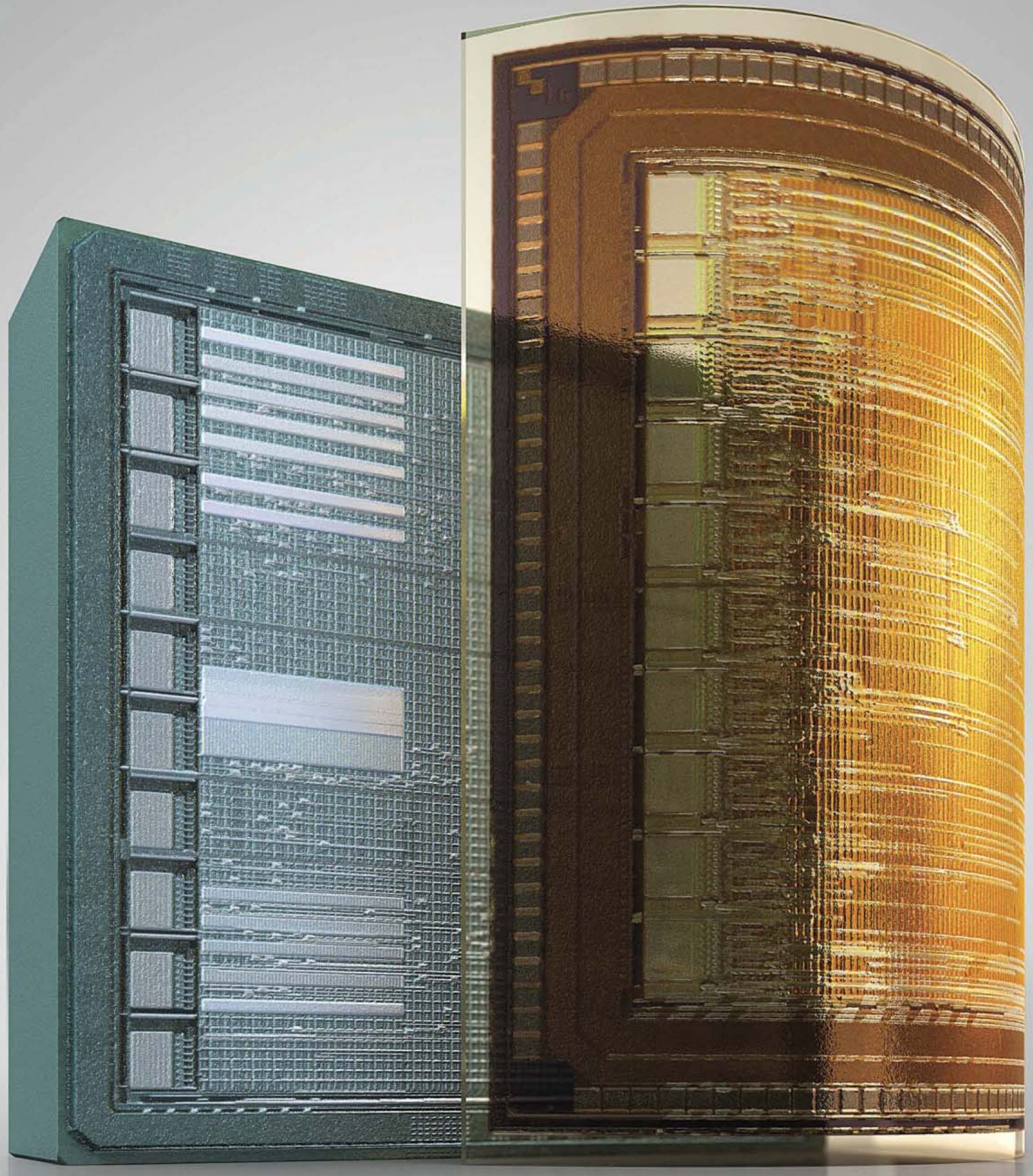


YOU CAN'T BE TOO THIN OR TOO FLEXIBLE

ULTRATHIN, FLEXIBLE SILICON TECHNOLOGY WILL IMPROVE 3-D CHIPS—AND A LOT MORE BESIDES

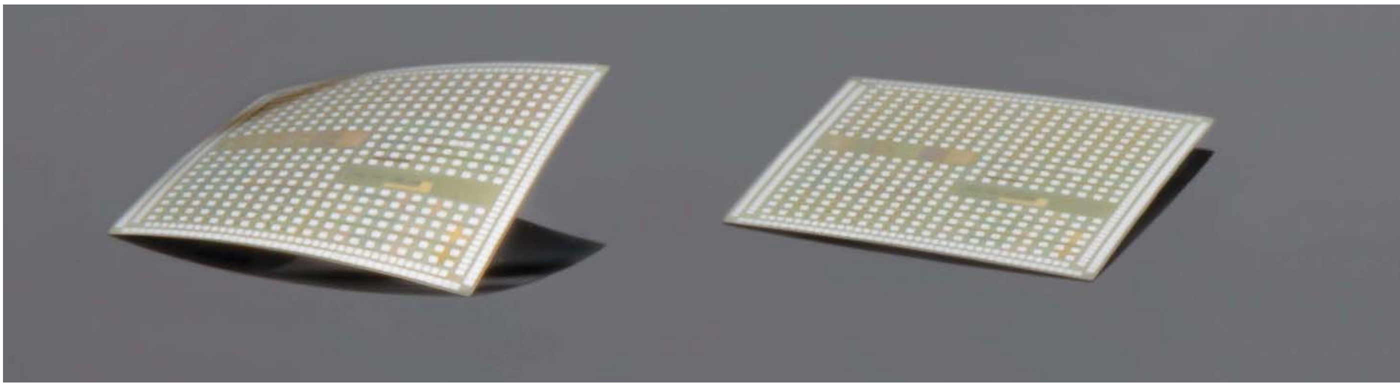
BY JOACHIM N. BURGHARTZ

IMAGINE RISING FROM BED to catch an early flight. As you head for the shower, still groggy, a tiny, flexible sensor chip in yesterday's clothes reminds you that they need to be washed. At breakfast, you check on your flight status and then stream the latest news to a tablet-size flexible display, flipping through pages of text and video. A message from your doctor pops up, reminding you to wear your medical diagnostic patch and pack your medication. As you leave your house, tiny sensors in the carpet and wallpaper put some appliances into standby mode. At the airport, a flexible electronic ticket guides you to the right gate, and a wireless interface between your ticket, your passport, and a retinal scanner gives you immediate clearance.

Such seamless integration of computing into everyday objects isn't quite here yet, in large part because we still don't have cheap, thin, flexible electronics. But the technology is already on a path toward ubiquity: radio frequency identification (RFID) tags are used to track goods (and, increasingly, pets and people), flexible sensors in car seats warn parents not to leave their babies behind when they go shopping, and bendable displays are on the way for e-readers. These inherently flexible products can be mass-produced, and some can even be printed, inkjet style, to create large displays.

Made primarily from nonsilicon organic and inorganic semiconductors, including polymers and metal oxide semiconductors, flexible chips are an exciting alternative to rigid silicon circuits in simple products like photovoltaic cells and television screens, because they can be made for a fraction of the cost. But today's flexible electronics just don't perform as well as silicon chips made the old-fashioned way. For example, in February 2011 the first microprocessor made with organic semiconductors was introduced, but the

ILLUSTRATION BY Bryan Christie Design



CHIP OFF THE OLD BLOCK: The guts of an integrated circuit lie near the surface, which is why you can dispense with a lot of excess silicon to get a light, bendable chip.

4000-transistor, 8-bit logic circuit operated at a clock frequency below 10 Hz. Compare that with the Intel 4004, introduced in 1971, which worked at 100 kilohertz and above—four orders of magnitude as fast.

A new technique for creating ultrathin silicon chips, though, could lead to many high-performance flexible applications, including displays, sensors, wireless interfaces, energy harvesting, and wearable biomedical devices. Silicon is an ideal semiconductor for such chips because its ordered structure allows for well-behaved switches that are far faster than organic alternatives.

So how do we get the best of both worlds? By combining today's cheap, large-scale flexible electronics with silicon that's just as powerful as the best available today—but thinner.

TODAY'S SILICON CHIPS are usually built on wafers up to a millimeter thick. In this bulky state, the wafers are stiff and stable enough to survive the fabrication process. Slimmed down to thicknesses of 100 to 300 micrometers, silicon wafers are still stiff, but they must be handled carefully. Between 50 and 100 μm, a wafer may fracture under its own weight.

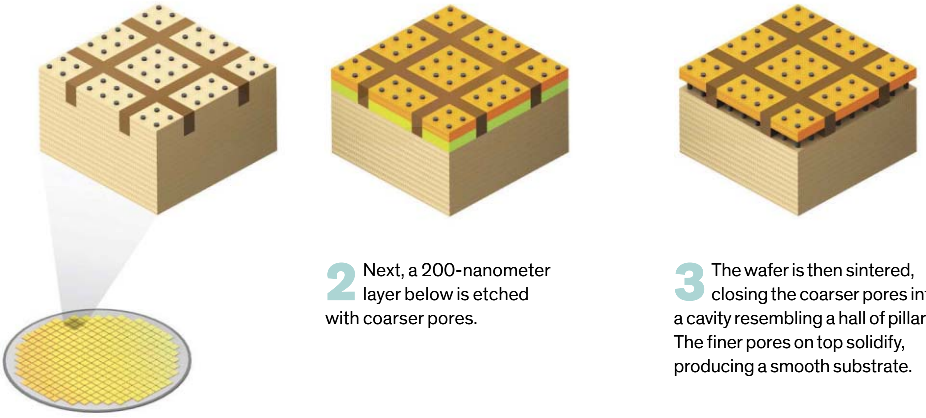
Strangely, though, below 50 μm, silicon chips hit a sweet spot: They get more flexible and more stable. Below 10 μm, a silicon chip even becomes optically transparent, which eases the alignment of chips during assembly and allows for their use as sensors on windows and other transparent surfaces. These sub-50-μm chips are ideal for the futuristic thin-film electronic applications I described above. They're able to bend, twist, and roll up, yet they're as strong as stainless steel—after all, they're still made of high-performance crystalline silicon.

And thinness enhances stackability. This is a critical attribute, given the advent of the three-dimensional integrated circuit, or 3-D IC. As chips become more complex and dense with transistors, the metal interconnects between the transistors grow longer and more convoluted. The purpose of stacking is to shorten the distance between transistors by connecting them vertically using through-silicon vias, thus speeding performance. That's just what flash memory designers are trying to do right now.

The current generation of 3-D flash memory ICs is built from stacks of 30-μm-thick chips. But to accommodate the smaller transistors that are on the way, chips will need to get even thinner. When that happens, they'll be ready to support a whole new world of applications. In combination with thin-film electronics, ultrathin silicon chips can be placed on a flexible substrate (commonly a polymer foil, but also paper or even cloth) to form a hybrid system-in-foil (SiF) device. The resulting thin but highly integrated circuits can provide all the muscle needed to diagnose our ills, choreograph our household appliances, and ease our early morning travel.

INSTITUT FÜR MIKROELEKTRONIK

The Chipfilm process builds ultrathin chips on stilts, then snaps them off.

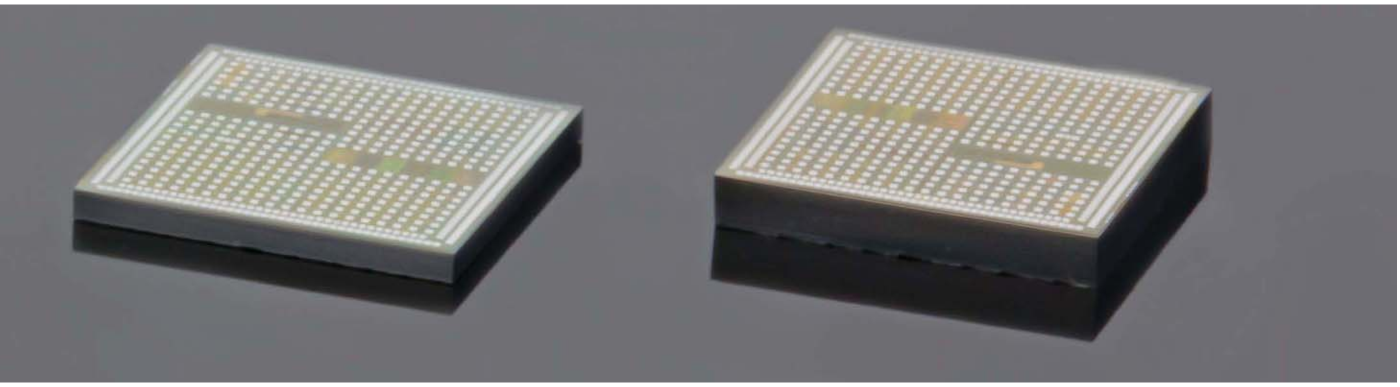


1 First, a fine, porous layer [inset] is etched onto the top micrometer of a silicon wafer [bottom].

2 Next, a 200-nanometer layer below is etched with coarser pores.

3 The wafer is then sintered, closing the coarser pores into a cavity resembling a hall of pillars. The finer pores on top solidify, producing a smooth substrate.

ILLUSTRATION BY Bryan Christie Design



OBTAINING ULTRATHIN SILICON CHIPS isn't a simple proposition. Typically, the chips are cut from large, pizza-size wafers of ultrapure silicon. The electronics reside in the upper 5 to 10 μm of the disk–the top 1 percent, that is. The rest serves as a sturdy base that can withstand the rigors of the automated fabrication line.

The most straightforward way to make a thin chip is to grind away that base. Conveniently, this can be done after the circuits are drawn and before the wafers are diced into chips, so that the sturdy substrate is still present during processing. This subtractive technique was the first strategy suggested by the International Technology Roadmap for Semiconductors in 2005, when it began to account for wafer thinning.

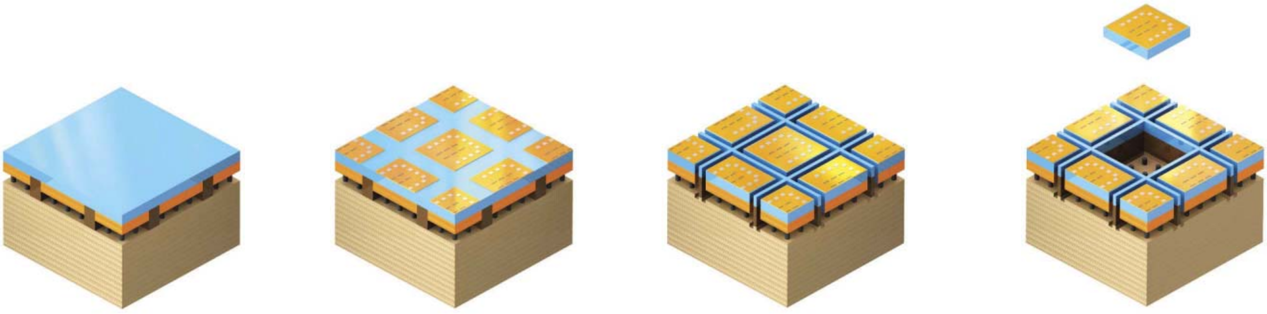
But grinding and dicing aren't gentle; they introduce crystalline defects and cracks at the edges of the wafer. There are work-arounds that can protect the wafer, but below 50 μm these steps become prohibitively expensive. As wafers get thinner, it's also more difficult to grind them to a uniform thickness across their entire diameter. Chipmakers must stabilize extremely thin wafers, gluing them temporarily to silicon or glass wafers, known as carriers; mounting and removing those carriers is an expensive process.

Another way to slim down a chip is by building a thin film of silicon on a layer of oxide, which itself lies on a thick silicon substrate. These silicon-on-insulator (SOI) wafers–so-called because silicon oxide is a wonderful insulator–lend themselves to processes that remove silicon selectively and uniformly. SOI wafers cost about 10 times as much as conventional wafers, however, and as with the wafer-grinding technique, they require extra substrates during handling. On top of these practical difficulties, both subtractive techniques waste 99 percent of the silicon wafer. It's like a baker throwing away the bottoms of his muffins and selling only the crunchy tops.

The alternative is to build the thin chip from the ground up. It's a radical solution, one that runs counter to half a century of chipmaking, but as applications require thinner and thinner chips, the much less wasteful additive technique looks better and better.

AT THE INSTITUT FÜR MIKROELEKTRONIK STUTTGART, in Germany, we are developing just such an additive technique, under the trade name Chipfilm. It entails growing crystalline silicon, layer by layer, on a foundation laced with sealed cavities. For this scheme, we attach the crystalline silicon layer to an array of small anchors, ensuring that the foundation will be strong enough to support the chip throughout the processing but weak enough to let us snap the finished chip off the top of the wafer. Then we can reuse the bulk of the silicon as a substrate.

We begin by etching a 1-μm layer of porous silicon onto a solid wafer and then a second, 200-nanometer layer of more coarsely porous



4 The fabricators then build a thin layer of crystalline silicon on the substrate to carry the electronic devices.

5 Standard lithographic methods can now be used to construct integrated circuits on the crystalline top layer.

6 The next step is to etch trenches right through to the underlying cavity, thus leaving the structure perched on top of the pillars.

7 Finally, a pick-and-place tool grabs the chip from above, snaps it off the pillars and removes it from the wafer.

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silicon underneath that. Next, we sinter both layers at high temperature, which causes the nanopores in the coarse layer to merge, like tiny soapsuds fusing into larger bubbles. That fusion closes the coarser pores in the lower layer, producing one continuous cavity interrupted by vertical pillars.

A RADICAL SOLUTION, ONE THAT RUNS COUNTER TO HALF A CENTURY OF CHIPMAKING, IS TO BUILD THE CHIP FROM THE GROUND UP.

The surface layer serves as a seed for the crystalline silicon, which we grow over the entire surface of the wafer to the desired thickness. Then the chip goes through typical processing–the hundreds of steps needed to create the electronic transistor functions and metal interconnects in and on the chip. After fabrication is complete, the surface layer is still firmly attached to the thick silicon wafer by the array of pillars within the buried cavity.

To snap the chip off the base, we etch a deep trench at the edges of the chip and down into the cavity. That leaves the chip attached to–and supported by–the pillars alone. Our process then makes novel use of a well-known instrument, the pick-and-place tool. This vacuum gripper is typically used to pick up and transfer chips, but we use it to grab the chip and tug it, snapping the vertical pillars with mechanical force. It's not hard to do, because of the presence of the trench.

By that point, the pillars will have done their job, which is to keep the chip intact during the many fabrication steps that would otherwise ruin a chip as thin as ours. As the chip is always attached to something–either a substrate or the vacuum gripper–it never breaks or rolls up. The pick-and-place tool can then place each chip onto a stack or a flexible substrate with other thin-film components.

AFTER REMOVING THE CHIPS, we can polish and recondition the original wafer so that the process can begin again. Each repetition thins down the wafer, but the recycling can go on for quite a while before the wafer becomes too delicate to handle. A 1-millimeter-thick wafer could be whittled down to as little as 400 μm, producing about 50 layers, each of which yields many thin chips. We throw out the remaining stub, but with this technique we waste far less silicon than we do with the subtractive techniques I mentioned earlier.

Subtractive techniques do sometimes have a logistical advantage, because they can be applied after the chip has been fabricated. But because a fully processed silicon wafer is about 100 times as valuable as a virgin silicon wafer, this advantage is realized only if the downstream grinding processes have a high success rate. Those success rates, as we've pointed out, decline as chips get thinner and thinner. By contrast, an additive approach shifts most of the thinning steps to the beginning, when any mistakes would ruin an unprocessed wafer rather than a valuable completed one. Another thing: When you're building from the ground up, the thinner the chip, the cheaper it is to make. That relationship is precisely the opposite of what you get with the subtractive techniques.

Put it all together and the costs and benefits still favor subtractive techniques for chips that are more than 100 μm thick–about the thickness used in today's smart cards. But for chips less than 30 μm thick–a size ideal for both 3-D ICs and large, flexible SiF applications–the additive approach appears to be more cost-effective.

INTRODUCING A NEW TECHNOLOGY is always a chicken-and-egg problem: Which should come first, the technology or the application? In the case of ultrathin chips, that question has already been answered, to a certain degree, by the industry's commitment to 3-D ICs. To sustain the miniaturization of microelectronics, the industry road map calls for 5- to 10-μm-thick chips to be used as layers in 3-D stacks by 2020. Chipmakers have a way to go to meet that goal; the thinnest chips currently being made by subtractive techniques in an industrial setting are 50 μm thick.

Our Chipfilm process can make chips as thin as 10 μm, but it isn't yet ready for large-scale production. For example, because the sintering process leaves some tiny bumps on the upper seed surface, the crystalline silicon that grows on it can develop slight defects or stacking faults. By optimizing the sintering conditions along with the thickness and porosity of the upper silicon layer, we will improve the quality of silicon that grows above it and the circuits we can make. We're also optimizing the final-stage cracking technique, which damages 5 percent of the chips, to improve yields even further.

Even after our ultrathin chips are finished, however, there are further hurdles for them to clear. Their prized flexibility makes them hard to attach to a substrate. Bubbles can form between the substrate and the chip, like the ones that sometimes get trapped between a protective film and a touch screen. If pressure is then applied to the chip, those bubbles can fracture the die.

These challenges should be surmountable in the seven years the road map for 3-D chips gives us. Meanwhile, the race to develop such chips will drive other applications of ultrathin chips. By 2020, the market for e-paper tablets and other high-performance displays will likely be large enough to call for ultrathin silicon chips. In the meantime, we can greatly improve the reliability of flexible-chip applications like RFID and electronic tags for currency and security documents if the chips are as thin and flexible as the foil patch on which they're mounted.

Then come the truly mind-boggling applications. Because ultrathin chips can be cut in many shapes, they could be especially useful for biomedical applications. Circular chips are desirable for retinal implants, miniature endoscopic cameras, and diagnostic video pills. Thin, flexible chips may even have the potential to interface with the brain, collecting or stimulating neural activity, perhaps even augmenting our mental powers. Such an interface would be very hard to implement, but one thing is clear: It would require chips of surpassing thinness, the only kind that can move with brain tissue without harming it.

Those applications are many years off. But until then, I'll be happy to settle for a dirty-laundry alert. ■

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1999–PRESENT

The author has been designing and wearing computerized eyewear for decades, the gear increasing markedly in sophistication over time.

What I've learned from 35 years of wearing computerized eyewear

By Steve Mann


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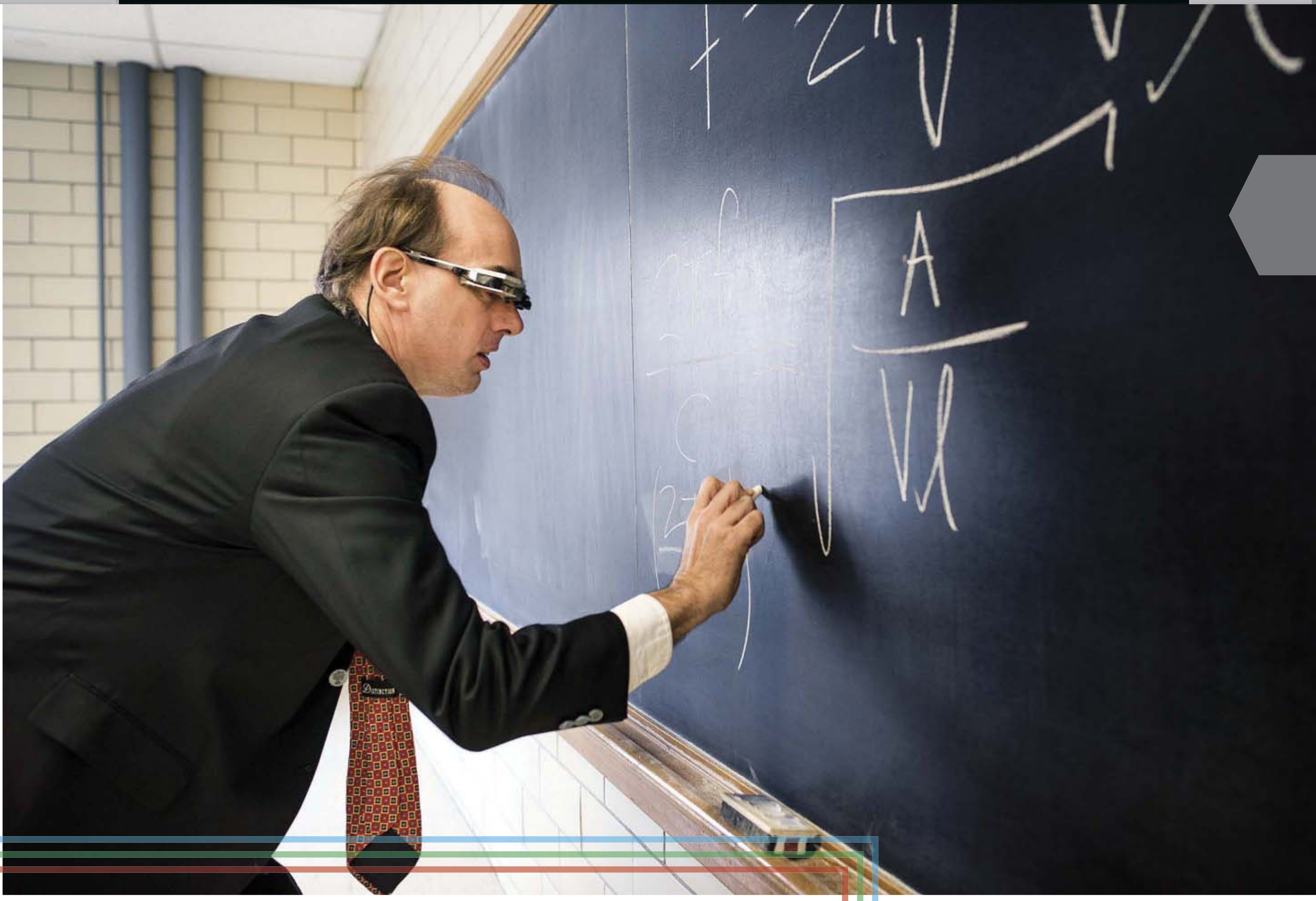


BACK IN 2004, I was awakened early one morning by a loud clatter. I ran outside, only to discover that a car had smashed into the corner of my house. As I went to speak with the driver, he threw the car into reverse and sped off, striking me and running over my right foot as I fell to the ground. When his car hit me, I was wearing a computerized-vision system I had invented to give me a better view of the world. The impact and fall injured my leg and also broke my wearable computing system, which normally overwrites its memory buffers and doesn't permanently record images. But as a result of the damage, it retained pictures of the car's license plate and driver, who was later identified and arrested thanks to this record of the incident.

Was it blind luck (pardon the expression) that I was wearing this vision-enhancing system at the time of the accident? Not at all: I have been designing, building, and wearing some form of this gear for more than 35 years. I have found these systems to be enormously empowering. For example, when a car's headlights shine directly into my eyes at night, I can still make out the driver's face clearly. That's because the computerized system combines multiple images taken with different exposures before displaying the results to me.

I've built dozens of these systems, which improve my vision in multiple ways. Some versions can even take in other spectral bands. If the equipment includes a camera that is sensitive to long-wavelength infrared, for example, I can detect subtle heat signatures, allowing me to see which seats in a lecture hall had just been vacated, or which cars in a parking lot most recently had their engines switched off. Other versions enhance text, making it easy to read signs that would otherwise be too far away to discern or that are printed in languages I don't know.

Believe me, after you've used such eyewear for a while, you don't want to give up all it offers. Wearing it, however, comes with a price. For one, it marks me as a nerd. For another, the early prototypes were hard to take on and off. These versions had an aluminum frame that wrapped tightly around the wearer's head, requiring special tools to remove.

Because my computerized eyewear can augment the dark portions of what I'm viewing while diminishing the amount of light in the bright areas, I say that it provides a "mediated" version of reality. I began using this phrasing long before the rise in popularity of the more widespread term "augmented reality," which usually refers to something less interesting: the overlay of text or graphics on top of your normal vision. That doesn't improve your eyesight. Indeed, it often makes it worse by obscuring your view with a lot of visual clutter.

For a long time, computer-aided vision and augmented reality were rather obscure topics, of interest only to a few corporate researchers, academics, and a small number of passionate hobbyists. Recently, however, aug-

PHOTOGRAPHS, PREVIOUS PAGES AND THIS PAGE BY Ryan Enn Hughes

SEEING THE SOLUTION: The author wears his Generation 4 glass during one of his lectures at the University of Toronto.

mented reality has captured the public consciousness. In particular, Google has lately attracted enormous attention to its Project Glass, an eyeglass-like smartphone with a wearable display. I suppose that's fine as far as it goes. But Google Glass is much less ambitious than the computer-mediated vision systems I constructed decades ago. What Google's involvement promises, though, is to popularize this kind of technology.

It's easy to see that coming: Wearable computing equipment, which also includes such items as health monitors and helmet-cams, is already close to a billion-dollar industry worldwide. And if Google's vigorous media campaign for its Project Glass is any indication of the company's commitment, wearable computers with head-mounted cameras and displays are poised finally to become more than a geek-chic novelty.

So here, then, let me offer some wisdom accumulated over the past 35 years. The way I figure it, thousands of people are about to experience some of the same weird sensations I first encountered decades ago. If I can prevent a few stumbles, so much the better.

THE IDEA OF BUILDING something to improve vision first struck me during my childhood, not long after my grandfather (an inveterate tinkerer) taught me to weld. Welders wear special goggles or masks to view their work and to protect their eyesight from the blindingly bright light, often from an electric arc. Old-fashioned welding helmets use darkened glass for this. More modern ones use electronic shutters. Either way, the person welding merely gets a uniformly filtered view. The arc still looks uncomfortably bright, and the surrounding areas remain frustratingly dim.

This long-standing problem for welders got me thinking: Why not use video cameras, displays, and computers to modify your view in real time? And why not link these wearable computer systems to centralized base stations or to one another? That would make them that much more versatile.

I started exploring various ways to do this during my youth in the 1970s, when most computers were the size of large rooms and wireless data networks were unheard of. The first versions I built sported separate transmitting and receiving antennas, including rabbit ears, which I'm sure looked positively ridiculous atop my head. But building a wearable general-purpose computer with wireless digital-communications capabilities was itself a feat. I was proud to have pulled that off and didn't really care what I looked like.

My late-1970s wearable computer systems evolved from something I first designed to assist photographers into units that featured text, graphics, video, audio, even radar capability by the early 1980s. As you can imagine, these required me to carry quite a bit of gear. Nearly everybody around me thought I was totally loony to wear all that hardware strapped to my head and body. When I was out with it, lots of people crossed the street to avoid me—including some rather unsavory-looking types who probably didn't want to be seen by someone wearing a camera and a bunch of radio antennas!

Why did I go to such extremes? Because I realized that the future of computing was as much about communications between people wearing computers as it was about performing colossal calculations. At the time, most engineers working with computers considered that a crazy notion. Only after I went to MIT for graduate school in the early 1990s did some of the people around me begin to see the merits of wearable computing.

The technical challenges at the time were enormous. For example, wireless data networks, so ubiquitous now, had yet to blossom. So I had to set up my own radio stations for data communications. The radio links I cobbled together in the late 1980s could transfer data at a then-blazing 56 kilobytes per second.

A few years before this, I had returned to my original inspiration—better welding helmets—and built some that incorporated vision-enhancing technology. While welding with such a helmet, I can discern the tip of the brilliant electrode, even the shape of the electric arc, while simultaneously seeing details of the surrounding areas. Even objects in the background, which would normally be swallowed up in darkness, are visible. These helmets exploit an image-processing

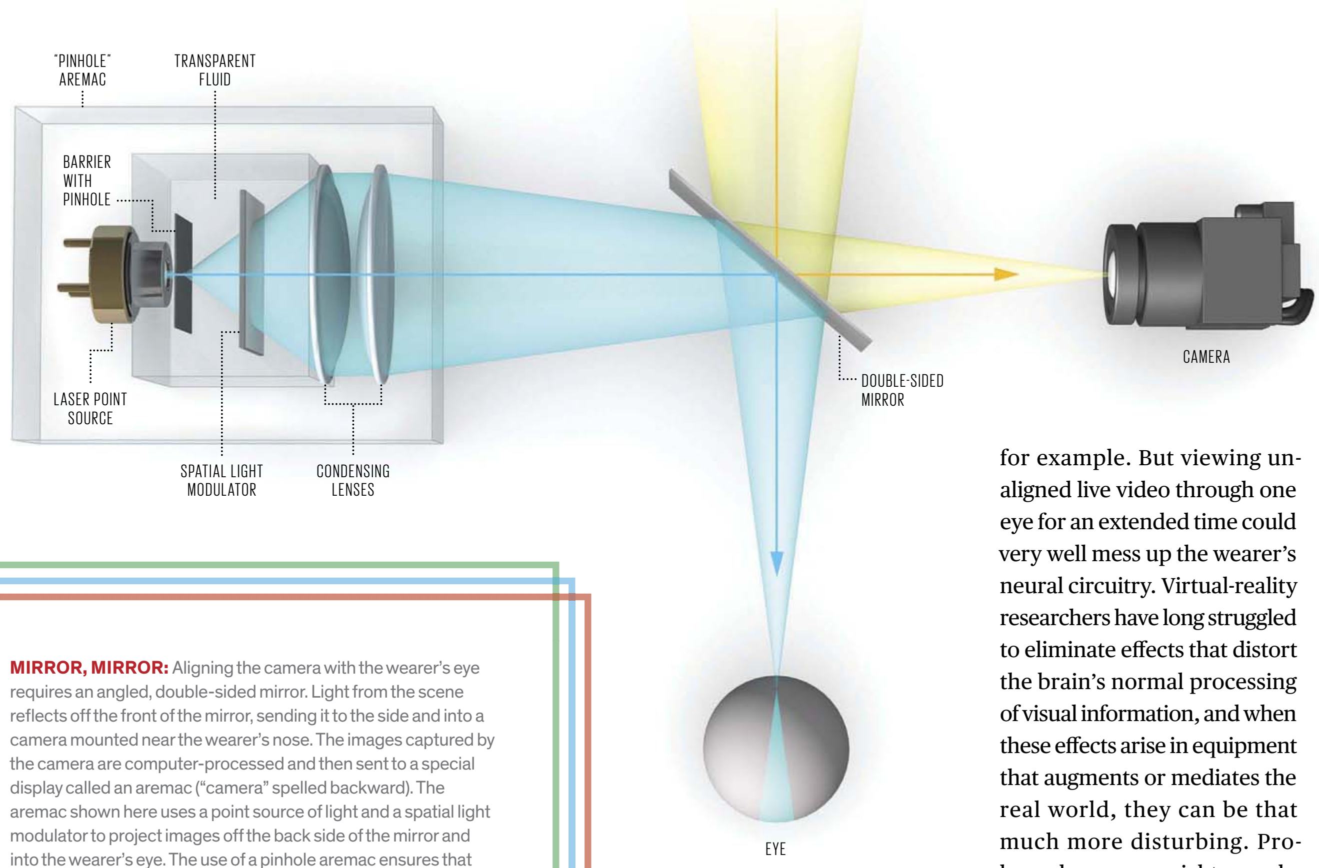
TAKE ME HOME: Each of these street views shows a portion of what is seen through the author's computerized vision system when it's running a way-finding application.

technique I invented that is now commonly used to produce HDR (high-dynamic-range) photos. But these helmets apply the technique at a fast video rate and let the wearer view the stereoscopic output in real time.

Welding was only one of many early applications for my computer-aided vision systems, but it's been influential in shaping how I've thought about this technology all along. Just as welders refer to their darkened glass in the singular, I call my equipment "Digital Eye Glass" rather than "digital eyeglasses," even for the units I've built into what look like ordinary eyeglasses or sunglasses. That Google also uses the singular "Glass" to describe its new gizmo is probably no coincidence.

I HAVE MIXED feelings about the latest developments. On one hand, it's immensely satisfying to see that the wider world now values wearable computer technology. On the other hand, I worry that Google and certain other companies are neglecting some important lessons. Their design decisions could make it hard for many folks to use

STEVE MANN AND RAYMOND LO (2)



MIRROR, MIRROR: Aligning the camera with the wearer's eye requires an angled, double-sided mirror. Light from the scene reflects off the front of the mirror, sending it to the side and into a camera mounted near the wearer's nose. The images captured by the camera are computer-processed and then sent to a special display called an aremac ("camera" spelled backward). The aremac shown here uses a point source of light and a spatial light modulator to project images off the back side of the mirror and into the wearer's eye. The use of a pinhole aremac ensures that the images remain sharp, no matter how the eye's lens is focused.

these systems. Worse, poorly configured products might even damage some people's eyesight and set the movement back years.

My concern comes from direct experience. The very first wearable computer system I put together showed me real-time video on a helmet-mounted display. The camera was situated close to one eye, but it didn't have quite the same viewpoint. The slight misalignment seemed unimportant at the time, but it produced some strange and unpleasant results. And those troubling effects persisted long after I took the gear off. That's because my brain had adjusted to an unnatural view, so it took a while to readjust to normal vision.

Research dating back more than a century helps explain this. In the 1890s, the renowned psychologist George Stratton constructed special glasses that caused him to see the world upside down. The remarkable thing was that after a few days, Stratton's brain adapted to his topsy-turvy worldview, and he no longer saw the world upside down. You might guess that when he took the inverting glasses off, he would start seeing things upside down again. He didn't. But his vision had what he called, with Victorian charm, "a bewildering air."

Through experimentation, I've found that the required readjustment period is, strangely, shorter when my brain has adapted to a dramatic distortion, say, reversing things from left to right or turning them upside down. When the distortion is subtle–a slightly offset viewpoint, for example–it takes less time to adapt but longer to recover.

The current prototypes of Google Glass position the camera well to the right side of the wearer's right eye. Were that system to overlay live video imagery from the camera on top of the user's view, the very same problems would surely crop up. Perhaps Google is aware of this issue and purposely doesn't feed live video back to the user on the display. But who knows how Google Glass will evolve or what apps others will create for it?

They might try to display live video to the wearer so that the device can serve as a viewfinder for taking pictures or video, for example. But viewing unaligned live video through one eye for an extended time could very well mess up the wearer's neural circuitry. Virtual-reality researchers have long struggled to eliminate effects that distort the brain's normal processing of visual information, and when these effects arise in equipment that augments or mediates the real world, they can be that much more disturbing. Prolonged exposure might even do permanent damage, particularly to youngsters, whose brains and eye muscles are still developing.

Google Glass and several similarly configured systems now in development suffer from another problem I learned about 30 years ago that arises from the basic asymmetry of their designs, in which the wearer views the display through only one eye. These systems all contain lenses that make the display appear to hover in space, farther away than it really is. That's because the human eye can't focus on something that's only a couple of centimeters away, so an optical correction is needed. But what Google and other companies are doing–using fixed-focus lenses to make the display appear farther away–is not good.

Using lenses in this way forces one eye to remain focused at some set distance while the focus of the other eye shifts according to whatever the wearer is looking at, near or far. Doing this leads to severe eyestrain, which again can be harmful, especially to children.

I HAVE CONSTRUCTED four generations of Digital Eye Glass in the course of figuring out how to solve this and other problems. While my latest hardware is quite complicated, the basic principles behind it are pretty straightforward.

ILLUSTRATION BY Emily Cooper

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Many of my systems, like Google Glass, modify the view of just one eye. I find this works well. But I arrange the optics so that the camera takes in exactly the same perspective as that eye does. I also position the display so that the wearer sees it directly ahead and doesn't have to look up (as is necessary with Google Glass), down, or sideways to view it.

Getting a good alignment of views isn't complicated–a double-sided mirror is all it takes. One surface reflects incoming light to a side-mounted camera; the other reflects light from a side-mounted display to the eye. By adding polarizing filters, you can use a partially transparent mirror so that whatever is presented on the display exactly overlays the direct view through that eye. Problem No. 1 solved.

The second issue, the eyestrain from trying to focus both eyes at different distances, is also one I overcame–more than 20 years ago! The trick is to arrange things so that the eye behind the mirror can focus at any distance and still see the display clearly. This arrangement of optical components is what I call an "aremac." (*Aremac* is just *camera* spelled backward.) Ideally, you'd use a pinhole aremac.

To appreciate why a pinhole aremac neatly solves the focusing problem, you first need to understand how a pinhole camera works. If you don't, consider this thought experiment. Imagine you want to record a brightly lit scene outside your window on a piece of photographic film. You can't just hold the film up and expect to get a clear image on it–but why not? Because light rays from every point in the scene would fall on every point on your film, producing a complete blur. What you want is for the light coming from each small point in the scene to land on a corresponding point on the film.

You can achieve that using a lightproof barrier with a tiny hole in it. Just put it between the scene and the film. Now, of all the light rays emanating from the upper-left corner of the scene, for instance, only one slips through the hole in the barrier, landing on the lower-right corner of the film in this case. Similar things happen for every other point in the scene, leading to a nice crisp (albeit inverted) image on the film.

Few cameras use pinholes, of course. Instead, they use lenses, which do the same job of forming an image while taking in more light. But lenses have a drawback: Objects at different distances require different focus settings. Pinholes don't have that shortcoming. They keep everything in focus, near or far. In the jargon of photographers, they are said to have an infinite depth of field.

My pinhole aremac is the reverse of a pinhole camera: It ensures that you see a sharp image through the display, no matter how you focus your eyes. This aremac is more complicated than a barrier with a pinhole, though. It requires a laser light source and a spatial light modulator, similar to what's found inside many digital projectors. With it, you can focus both eyes normally while using one eye to look through the mediated-vision system, thus avoiding eyestrain.

It's astounding to me that Google and other companies now seeking to market head-wearable computers with cameras and displays haven't leapfrogged over my best design (something I call "EyeTap Generation-4 Glass") to produce models that are even better. Perhaps it's because no one else working on this sort of thing has spent years walking around with one eye that's a camera. Or maybe this is just another example of not-invented-here syndrome.

Post your comments online at http://spectrum.ieee.org/vision0313

UNTIL RECENTLY, most people tended to regard me and my work with mild curiosity and bemusement. Nobody really thought much about what this technology might mean for society at large. But increasingly, smartphone owners are using various sorts of augmented-reality apps. And just about all mobile-phone users have helped to make video and audio recording capabilities pervasive. Our laws and culture haven't even caught up with that. Imagine if hundreds of thousands, maybe millions, of people had video cameras constantly poised on their heads. If that happens, my experiences should take on new relevance.

The system I routinely use looks a bit odd, but it's no more cumbersome than Google Glass. Wearing it in public has, however, often brought me grief–usually from people objecting to what they think is a head-mounted video recorder. So I look forward to the day when wearing such things won't seem any stranger than toting around an iPhone.

Putting cameras on vast numbers of people raises important privacy and copyright issues, to be sure. But there will also be benefits. When police mistakenly shot to death Jean Charles de Menezes, a Brazilian electrician, at a London tube station in 2005, four of the city's ubiquitous closed-circuit television cameras were trained on the platform. Yet London authorities maintain that no video of the incident was recovered. A technical glitch? A cover-up? Either way, imagine if many of the bystanders were wearing eyeglass-like recording cameras as part of their daily routines. Everyone would know what happened.

GRAND DAY OUT: While a graduate student at MIT, the author experimented with wearable computing systems, including this rather ungainly 1996 arrangement.

RICHARD HOWARD/TIME LIFE PICTURES/GETTY IMAGES

But there's a darker side: Instead of acting as a counterweight to Big Brother, could this technology just turn us into so many Little Brothers, as some commentators have suggested? (I and other participants will be discussing such questions in June at the 2013 IEEE International Symposium on Technology and Society, in Toronto.)

I believe that like it or not, video cameras will soon be everywhere: You already find them in many television sets, automatic faucets, smoke alarms, and energy-saving lightbulbs. No doubt, authorities will have access to the recordings they make, expanding an already large surveillance capability. To my mind, surveillance videos stand to be abused less if ordinary people routinely wear their own video-gathering equipment, so they can watch the watchers with a form of inverse surveillance.

Of course, I could be wrong. I can see a lot of subtle things with my computerized eyewear, but the future remains too murky for me to make out. ■


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THE REAL STORY OF STUXNET

HOW KASPERSKY LAB TRACKED DOWN THE MALWARE THAT STYMIED IRAN'S NUCLEAR-FUEL ENRICHMENT PROGRAM

BY DAVID KUSHNER

COMPUTER CABLES SNAKE across the floor. Cryptic flowcharts are scrawled across various whiteboards adorning the walls. A life-size Batman doll stands in the hall. This office might seem no different than any other geeky workplace, but in fact it's the front line of a war–a cyberwar, where most battles play out not in remote jungles or deserts but in suburban office parks like this one. As a senior researcher for Kaspersky Lab, a leading computer security firm based in Moscow, Roel Schouwenberg spends his days (and many nights) here at the lab's U.S. headquarters in Woburn, Mass., battling the most insidious digital weapons ever, capable of crippling water supplies, power plants, banks, and the very infrastructure that once seemed invulnerable to attack.

Recognition of such threats exploded in June 2010 with the discovery of Stuxnet, a 500-kilobyte computer worm that infected the software of at least 14 industrial sites in Iran, including a uranium-enrichment plant.

ILLUSTRATION BY Brian Stauffer

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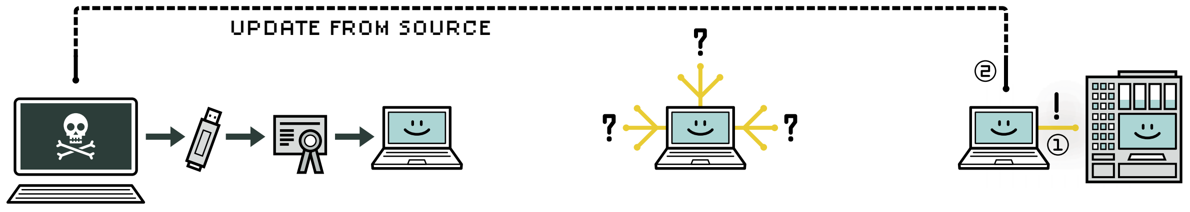
HOW STUXNET WORKED



1. INFECTION
Stuxnet enters a system via a USB stick and proceeds to infect all machines running Microsoft Windows. By brandishing a digital certificate that seems to show that it comes from a reliable company, the worm is able to evade automated-detection systems.

2. SEARCH
Stuxnet then checks whether a given machine is part of the targeted industrial control system made by Siemens. Such systems are deployed in Iran to run high-speed centrifuges that help to enrich nuclear fuel.

3. UPDATE
If the system isn't a target, Stuxnet does nothing; if it is, the worm attempts to access the Internet and download a more recent version of itself.

Although a computer virus relies on an unwitting victim to install it, a worm spreads on its own, often over a computer network.

This worm was an unprecedentedly masterful and malicious piece of code that attacked in three phases. First, it targeted Microsoft Windows machines and networks, repeatedly replicating itself. Then it sought out Siemens Step7 software, which is also Windows-based and used to program industrial control systems that operate equipment, such as centrifuges. Finally, it compromised the programmable logic controllers. The worm's authors could thus spy on the industrial systems and even cause the fast-spinning centrifuges to tear themselves apart, unbeknownst to the human operators at the plant. (Iran has not confirmed reports that Stuxnet destroyed some of its centrifuges.)

Stuxnet could spread stealthily between computers running Windows—even those not connected to the Internet. If a worker stuck a USB thumb drive into an infected machine, Stuxnet could, well, worm its way onto it, then spread onto the next machine that read that USB drive. Because someone could unsuspectingly infect a machine this way, letting the worm proliferate over local area networks, experts feared that the malware had perhaps gone wild across the world.

In October 2012, U.S. defense secretary Leon Panetta warned that the United States was vulnerable to a "cyber Pearl Harbor" that could derail trains, poison water supplies, and cripple power grids. The next month, Chevron confirmed the speculation by becoming the first U.S. corporation to admit that Stuxnet had spread across its machines.

Although the authors of Stuxnet haven't been officially identified, the size and sophistication of the worm have led experts to believe that it could have been created only with the sponsorship of a nation-state, and although no one's owned up to it, leaks to the press from officials in the United States and Israel strongly suggest that those two countries did the deed. Since the discovery of Stuxnet, Schouwenberg and other computer-security engineers have been fighting off other weaponized viruses, such as Duqu, Flame, and Gauss, an onslaught that shows no signs of abating.

This marks a turning point in geopolitical conflicts, when the apocalyptic scenarios once only imagined in movies like *Live Free or Die Hard* have finally become plausible. "Fiction suddenly became reality," Schouwenberg says. But the hero fighting against this isn't Bruce Willis; he's a scruffy 27-year-old with a ponytail. Schouwenberg tells me, "We are here to save the world." The question is: Does the Kaspersky Lab have what it takes?

VIRUSES WEREN'T ALWAYS this malicious. In the 1990s, when Schouwenberg was just a geeky teen in the Netherlands, malware was typically the work of pranksters and hackers, people looking to crash your machine or scrawl graffiti on your AOL home page.

After discovering a computer virus on his own, the 14-year-old Schouwenberg contacted Kaspersky Lab, one of the leading antivirus companies. Such companies are judged in part on how many viruses they are first to detect, and Kaspersky was considered among the best. But with its success came controversy. Some accused Kaspersky of having ties with the Russian government—accusations the company has denied.

A few years after that first overture, Schouwenberg e-mailed founder Eugene Kaspersky, asking him whether he should study math in college if he wanted to be a security specialist. Kaspersky replied by offering the 17-year-old a job, which he took. After spending four years working for the company in the Netherlands, he went to the Boston area. There, Schouwenberg learned that an engineer needs specific skills to fight malware. Because most viruses are written for Windows, reverse engineering them requires knowledge of *x*86 assembly language.

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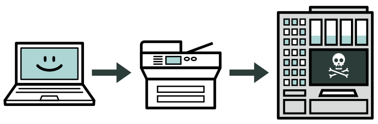

4. COMPROMISE
The worm then compromises the target system's logic controllers, exploiting "zero day" vulnerabilities—software weaknesses that haven't been identified by security experts.

5. CONTROL
In the beginning, Stuxnet spies on the operations of the targeted system. Then it uses the information it has gathered to take control of the centrifuges, making them spin themselves to failure.

6. DECEIVE AND DESTROY
Meanwhile, it provides false feedback to outside controllers, ensuring that they won't know what's going wrong until it's too late to do anything about it.

Over the next decade, Schouwenberg was witness to the most significant change ever in the industry. The manual detection of viruses gave way to automated methods designed to find as many as 250 000 new malware files each day. At first, banks faced the most significant threats, and the specter of state-against-state cyberwars still seemed distant. "It wasn't in the conversation," says Liam O'Murchu, an analyst for Symantec Corp., a computer-security company in Mountain View, Calif.

All that changed in June 2010, when a Belarusian malware-detection firm got a request from a client to determine why its machines were rebooting over and over again. The malware was signed by a digital certificate to make it appear that it had come from a reliable company. This feat caught the attention of the antivirus community, whose automated-detection programs couldn't handle such a threat. This was the first sighting of Stuxnet in the wild.

The danger posed by forged signatures was so frightening that computer-security specialists began quietly sharing their findings over e-mail and on private online forums. That's not unusual. "Information sharing [in the] computer-security industry can only be categorized as extraordinary," adds Mikko H. Hypponen, chief research officer for F-Secure, a security firm in Helsinki, Finland. "I can't think of any other IT sector where there is such extensive cooperation between competitors." Still, companies do compete—for example, to be the first to identify a key feature of a cyberweapon and then cash in on the public-relations boon that results.

Before they knew what targets Stuxnet had been designed to go after, the researchers at Kaspersky and other security firms began reverse engineering the code, picking up clues along the way: the number of infections, the fraction of infections in Iran, and the references to Siemens industrial programs, which are used at power plants.

Schouwenberg was most impressed by Stuxnet's having performed not just one but four zero-day exploits, hacks that take advantage of vulnerabilities previously unknown to the white-hat community. "It's not just a groundbreaking number; they all complement each other beautifully," he says. "The LNK [a file shortcut in Microsoft Windows] vulnerability is used to spread via USB sticks. The shared print-spooler vulnerability is used to spread in networks with shared printers, which is extremely common in Internet Connection Sharing networks. The other two vulnerabilities have to do with privilege escalation, designed to gain system-level privileges even when computers have been thoroughly locked down. It's just brilliantly executed."

Schouwenberg and his colleagues at Kaspersky soon concluded that the code was too sophisticated to be the brainchild of a ragtag group of black-hat hackers. Schouwenberg believes that a team of 10 people would have needed at least two or three years to create it. The question was, who was responsible?

It soon became clear, in the code itself as well as from field reports, that Stuxnet had been specifically designed to subvert Siemens systems running centrifuges in Iran's nuclear-enrichment program. The Kaspersky analysts then realized that financial gain had not been the objective. It was a politically motivated attack. "At that point there was no doubt that this was nation-state sponsored," Schouwenberg says. This phenomenon caught most computer-security specialists by surprise. "We're all engineers here; we look at code," says Symantec's O'Murchu. "This was the first real threat we've seen where it had real-world political ramifications. That was something we had to come to terms with."

IN MAY 2012, Kaspersky Lab received a request from the International Telecommunication Union, the United Nations agency that manages information and communication technologies, to

ILLUSTRATION BY L-Dopa

CYBERSLEUTH: Roel Schouwenberg, of Kaspersky Lab, helped unravel Stuxnet and its kin in the most sophisticated family of Internet worms ever discovered.

study a piece of malware that had supposedly destroyed files from oil-company computers in Iran. By now, Schouwenberg and his peers were already on the lookout for variants of the Stuxnet virus. They knew that in September 2011, Hungarian researchers had uncovered Duqu, which had been designed to steal information about industrial control systems.

While pursuing the U.N.'s request, Kaspersky's automated system identified another Stuxnet variant. At first, Schouwenberg and his team concluded that the system had made a mistake, because the newly discovered malware showed no obvious similarities to Stuxnet. But after diving into the code more deeply, they found traces of another file, called Flame, that were evident in the early iterations of Stuxnet. At first, Flame and Stuxnet had been considered totally independent, but now the researchers realized that Flame was actually a precursor to Stuxnet that had somehow gone undetected.

Flame was 20 megabytes in total, or some 40 times as big as Stuxnet. Security specialists realized, as Schouwenberg puts it, that "this could be nation-state again."

To analyze Flame, Kaspersky used a technique it calls the "sinkhole." This entailed taking control of Flame's command-and-control server domain so that when Flame tried to communicate with the server in its home base, it actually sent information to Kaspersky's server instead. It was difficult to determine who owned Flame's servers. "With all the available stolen credit cards and Internet proxies," Schouwenberg says, "it's really quite easy for attackers to become invisible."

While Stuxnet was meant to destroy things, Flame's purpose was merely to spy on people. Spread over USB sticks, it could infect printers shared over the same network. Once Flame had compromised a machine, it could stealthily search for keywords on top-secret PDF files, then make and transmit a summary of the document—all without being detected.

Indeed, Flame's designers went "to great lengths to avoid detection by security software," says Schouwenberg. He offers an example: Flame didn't simply transmit the information it harvested all at once to its command-and-control server, because network managers might notice that sudden outflow. "Data's sent off in smaller chunks to avoid hogging available bandwidth for too long," he says.

Most impressively, Flame could exchange data with any Bluetooth-enabled device. In fact, the attackers could steal information or install other malware not only within Bluetooth's standard 30-meter range but also farther out. A "Bluetooth rifle"—a directional antenna linked to a Bluetooth-enabled computer, plans for which are readily available online—could do the job from nearly 2 kilometers away.

MILESTONES IN MALWARE

1971 Creeper, an experimental self-replicating viral program, is written by Bob Thomas at Bolt, Beranek and Newman. It infected DEC PDP-10 computers running the Tenex operating system. Creeper gained access via the ARPANET, the predecessor of the Internet, and copied itself to the remote system, where the message "I'm the creeper, catch me if you can!" was displayed. The Reaper program was later created to delete Creeper.

1981 Elk Cloner, written for Apple II systems and created by Richard Skrenta, led to the first large-scale computer virus outbreak in history.

1986 The Brain boot sector virus (aka Pakistani flu), the first IBM PC–compatible virus, is released and causes an epidemic. It was created in Lahore, Pakistan, by 19-year-old Basit Farooq Alvi and his brother, Amjad Farooq Alvi.

1988 The Morris worm, created by Robert Tappan Morris, infects DEC VAX and Sun machines running BSD Unix connected to the Internet. It becomes the first worm to spread extensively "in the wild."

PHOTOGRAPH BY David Yellen

But the most worrisome thing about Flame was how it got onto machines in the first place: via an update to the Windows 7 operating system. A user would think she was simply downloading a legitimate patch from Microsoft, only to install Flame instead. "Flame spreading through Windows updates is more significant than Flame itself," says Schouwenberg, who estimates that there are perhaps only 10 programmers in the world capable of engineering such behavior. "It's a technical feat that's nothing short of amazing, because it broke world-class encryption," says F-Secure's Hypponen. "You need a supercomputer and loads of scientists to do this."

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If the U.S. government was indeed behind the worm, this circumvention of Microsoft's encryption could create some tension between the company and its largest customer, the Feds. "I'm guessing Microsoft had a phone call between Bill Gates, Steve Ballmer, and Barack Obama," says Hypponen. "I would have liked to listen to that call."

While reverse engineering Flame, Schouwenberg and his team fine-tuned their "similarity algorithms"—essentially, their detection code—to search for variants built on the same platform. In July, they found Gauss. Its purpose, too, was cybersurveillance.

Carried from one computer to another on a USB stick, Gauss would steal files and gather passwords, targeting Lebanese bank credentials for unknown reasons. (Experts speculate that this was either to monitor transactions or siphon money from certain accounts.) "The USB module grabs information from the system—next to the encrypted payload—and stores this information on the USB stick itself," Schouwenberg explains. "When this USB stick is then inserted into a Gauss-infected machine, Gauss grabs the gathered data from the USB stick and sends it to the command-and-control server."

Just as Kaspersky's engineers were tricking Gauss into communicating with their own servers, those very servers suddenly went down, leading the engineers to think that the malware's authors were quickly covering their tracks. Kaspersky had already gathered enough information to protect its clients against Gauss, but the moment was chilling. "We're not sure if we did something and the hackers were onto us," Schouwenberg says.

THE IMPLICATIONS of Flame and Stuxnet go beyond state-sponsored cyberattacks. "Regular cybercriminals look at something that Stuxnet is doing and say, that's a great idea, let's copy that," Schouwenberg says.

"The takeaway is that nation-states are spending millions of dollars of development for these types of cybertools, and this is a trend that will simply increase in the future," says Jeffrey Carr, the founder and CEO of Taia Global, a security firm in McLean, Va. Although Stuxnet may have temporarily slowed the enrichment program in Iran, it did not achieve its end goal. "Whoever spent millions of dollars on Stuxnet, Flame, Duqu, and so on—all that money is sort of wasted. That malware is now out in the public spaces and can be reverse engineered," says Carr.

Hackers can simply reuse specific components and technology available online for their own attacks. Criminals might use cyberespionage to, say, steal customer data from a bank or simply wreak havoc as part of an elaborate prank. "There's a lot of talk about nations trying to attack us, but we are in a situation where we are vulnerable to an army of 14-year-olds who have two weeks' training," says Schouwenberg.

The vulnerability is great, particularly that of industrial machines. All it takes is the right Google search terms to find a way into the systems of U.S. water utilities, for instance. "What we see is that a lot of industrial control systems are hooked up to the Internet," says Schouwenberg, "and they don't change the default password, so if you know the right keywords you can find these control panels."

Companies have been slow to invest the resources required to update industrial controls. Kaspersky has found critical-infrastructure companies running 30-year-old operating systems. In Washington, politicians have been calling for laws to require such companies to maintain better security practices. One cybersecurity bill, however, was stymied in August on the grounds that it would be too costly for businesses. "To fully provide the necessary protection in our democracy, cybersecurity must be passed by the Congress," Panetta recently said. "Without it, we are and we will be vulnerable."

In the meantime, virus hunters at Kaspersky and elsewhere will keep up the fight. "The stakes are just getting higher and higher and higher," Schouwenberg says. "I'm very curious to see what will happen 10, 20 years down the line. How will history look at the decisions we've made?" ■

1992 — Michelangelo is hyped by computer-security executive John McAfee, who predicted that on 6 March the virus would wipe out information on millions of computers; actual damage was minimal.

2003 — The SQL Slammer worm (aka Sapphire worm) attacks vulnerabilities in the Microsoft Structured Query Language Server and Microsoft SQL Server Data Engine and becomes the fastest spreading worm of all time, crashing the Internet within 15 minutes of release.

2010 — The Stuxnet worm is detected. It is the first worm known to attack SCADA (supervisory control and data acquisition) systems.

2011 — The Duqu worm is discovered. Unlike Stuxnet, to which it seems to be related, it was designed to gather information rather than to interfere with industrial operations.

2012 — Flame is discovered and found to be used in cyberespionage in Iran and other Middle Eastern countries.

CONTINUED FROM PAGE 32 | Watson's genome and he collaborated with German researchers to sequence a Neanderthal's DNA, using genetic material extracted from bone samples. But in 2007 the company was purchased by the biotech giant Roche Diagnostics, leaving Rothberg rich but jobless. He had to start again, and he needed a new idea.

That idea emerged from a fundamental problem that 454 and its competitors had experienced: Inventing a new sequencing technology had also meant creating a new supply chain. The companies all had to establish manufacturing processes for their machines and components, including the substrates, chemicals, and sophisticated optical instruments. "Everybody ran into trouble," Rothberg said. His next company, Rothberg decided, wouldn't just take inspiration from the semiconductor industry, it would also adopt its entire supply chain. He set out to design a semiconductor chip that could sequence DNA and be manufactured in a standard microchip foundry.

Rothberg found his solution, surprisingly, in a technology that's been around for four decades: the ion-sensitive field-effect transistor (ISFET). The electric current flowing through an ISFET submerged in a solution varies depending on the pH of that solution. Rothberg knew that adding a nucleotide to a growing DNA strand naturally releases a hydrogen ion, which makes the solution more acidic. It should be possible, he reasoned, to put many ISFETs in an array to detect the minute pH changes as As and Gs and so forth were added to a DNA strand. "This would be a sensor array that would literally see chemistry," Rothberg says with a proud grin.

With his new company, Ion Torrent, he built a machine that continued to rely on a plate covered with tiny wells. But instead of indicating the addition of nucleotides with flashes of light, the machine registered them by using an array of ISFETs to detect tiny changes in pH. The first chip he made was a dinky thing with an array of just 256 000 ISFET sensors, all aligned with wells containing pieces of DNA template. When the first nucleotide—say, an A—washed over the chip, all those template pieces that needed an A to complete the first rung of the ladder incorporated it. The ISFET sensors in those wells reacted to the change in pH, and their change in current was registered as digital information.

Rothberg's technology improved quickly: His second experimental chip had 1 million ISFET sensors, and he has kept on iterating. Increasing the number of sensors and wells means that more template pieces can be analyzed in parallel during a single run of the machine, making sequencing faster and cheaper. Ion Torrent's forthcoming chip, expected in mid-2013, will have 660 million wells, each with microfluidics on top and an ISFET sensor below.

In our conversations, Rothberg said his technology has improved so rapidly because he's "catching up with the accumulated Moore's Law," the five-decade-old dictum stating that the number of transistors on leading-edge ICs will double about every two years. To drive his point home, in July 2011 he used his machine to sequence the genome of none other than Gordon Moore, author of the eponymous law. It took 1000 chips to decode Moore's genome then. With Rothberg's next chip, it will take one.

On a tour of the Guilford labs, Rothberg pauses in front of his latest machine, the Ion Proton. "We'll have chips that have 2 billion

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and 5 billion sensors," he declares. "These machines are fully capable of enabling a $1000 genome. Then as we replace these disposable chips at higher and higher densities, we'll be able to drop that cost even further." Most of the cost comes from the single-use chip, which is tossed after a machine's run; the chemicals used are cheap.

Rothberg is convinced that he's a visionary. In general, objective observers agree. "When I first heard that Rothberg had developed a sequencing platform essentially by measuring pH, I was astounded, I was flabbergasted," says Kevin Davies, author of the recent book *The $1000 Genome* (Free Press, 2010). Davies praises Rothberg for his ability to knit together ideas from such disparate industries as chemistry, engineering, and software. "He pulls the threads together and makes them work," Davies adds. "That's his brilliance." However, Davies notes that there's plenty of excitement about other emerging technologies, including sequencing techniques that require only a single molecule of DNA to work. Several biotech companies, including Oxford Nanopore Technologies, in England, and Genia Corp., in California, are racing to commercialize those.

Robert Darnell, president of the New York Genome Center, says that Ion Torrent's technology is fascinating, but he stops short of calling it the market leader. The New York center, just established, will provide genome-sequencing services to New York's biggest medical and research institutions, and Darnell's team is therefore buying a lot of machines. After a "careful assessment," Darnell says, his organization decided to purchase 25 sequencing machines from Illumina, a biotech concern in San Diego. But the genome center will also try out newer machines, including Ion Torrent's Proton. The situation is changing so fast, Darnell said, that today's market leader could be forgotten in a couple of years. "There could be a disruptive technology at any point," he concludes.

In November, I'm back in Houston to get my results. I'm about to learn whether there's a genetic killer, or even a genetic pest, lurking within me.

While an Ion Torrent machine can sequence an exome in just a few hours, I found that the process slows down considerably when a hospital gets involved. For one thing, the machine's software can identify gene variants of possible interest, but that raw data must then be scrutinized by experts. And my results had to be certified as medically accurate to meet the hospital's stringent standards, which meant checking and double-checking. Lupski smiles across the table and says, "It's a $1000 genome but a $100 000 analysis."

These genetic results would ordinarily go to my physician, who would interpret them for me in light of my family medical history. The Baylor researchers don't know that history, so they've pulled out everything that seems possibly significant. I'll have to tell them if any of the findings match ailments that have afflicted my family members. "Okay, lay it on me," I say.

The doctors hand me a six-page report with scary words that jump out: Parkinson's, kidney failure, cardiomyopathy (a deterioration of the heart muscles). The doctors hurry to put these findings in context. "We did not find anything that requires immediate medical attention," says Christine Eng, the physician and researcher who heads Baylor's commercial genomics lab. That's a relief. While I do have mutations in genes that are known to be associated with these life-ending maladies, my particular type of mutations haven't been proved to cause a single tremor or irregular heartbeat.

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Still, these findings are red flags, and one of those flags is waving in the breeze. My paternal grandfather's kidneys failed toward the end of his life, I tell the doctors. Could he have had this same mutation?

"Aha," Eng says, scribbling a note on her copy of the report. "This would be a situation where if we had more information from your family, we could rule this in or out as being significant for you." If my doctor can get access to my grandfather's medical records, she says, he can determine whether I'm likely to develop this particular kidney disease and come up with a monitoring plan. As I sit here with some of the nation's top practitioners of genetic medicine, I imagine a future in which my exome data is integrated into my electronic medical records. At my first mention of kidney-related symptoms, a genetic alert for my doctor would pop up.

We go over the rest of the report, discussing a few recessive diseases that I seem to be a carrier for: There is something called Usher syndrome, for example, which typically causes congenital deafness. But I don't know of any deafness in my family. And that's about it. If the project shows the potential of personalized genetic medicine, it also demonstrates its current limitations. "There's still a lot more that we have to learn," admits Lupski. The crystal ball has turned up a lot of possibilities, and a few shadowy grim reapers are waving from the murky depths. But the results probably won't change my life in any meaningful way.

When I tell my parents the results, I can't help sounding disappointed. "It's reassuring," I say when we gather around the kitchen table. "But I expected to find out more that seemed relevant to our family." My mother asks if I would recommend an exome scan to others, and I say no, not unless they're trying to answer a specific medical question. It doesn't make sense now for healthy people to run out and get their exomes sequenced, because you just don't find out enough that's "medically actionable," as the Baylor doctors would put it. But the situation is changing incredibly fast. "Ten years down the line it might make sense," I tell my mom.

Then comes a surprise that casts doubt on my first judgment and forces me to see exome sequencing in a new light. In the weeks following my meeting at Baylor I idly Google the various conditions listed in the report the doctors gave me. One afternoon I type in "Usher syndrome" and follow a link to a National Institutes of Health Web page about the disorder. A few sentences in, I feel a shock of recognition. The syndrome, I read, is associated not just with deafness but also with night blindness and severe balance problems. My mother has been completely unable to see in the dark for as long as she can remember, and both she and her older brother have gotten dangerously wobbly on their feet over the past decade.

I go back to talk to my mother again, and she gasps at my recitation of symptoms: "Oh my gosh, I've got that! And my brother too!" But as soon as she has internalized the news, she asks the inevitable question: Can anything be done about it? Not much, I tell her. She would have to undergo a genetic test of her own to see if she really does have a form of Usher's, and even a definitive diagnosis wouldn't lead to a treatment, because there are none. "You're at the frontier of genetic medicine," I say, partly because I don't know what else to say. "It's very rare that a patient can go to the doctor saying, 'I know about my genes, and now you have to build your treatment plan around my genetic knowledge.' " She could be monitored for further vision loss, I offer.

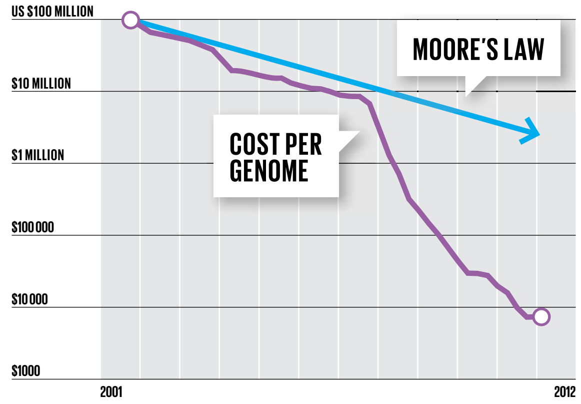
I return to Guilford one more time to talk over my exome results with Rothberg. He flips the pages of my report with curiosity and listens as I explain that I'd hoped the scan would give me more prompts to take action. That's what comes of being an early adopter, Rothberg says. "We're at a tipping point," he adds, "and we're just starting to sequence individuals. So we don't have a lot of information that correlates your sequence with outcome. Right now there's only a handful of genes that we can tell you something about."

But, he goes on, every day new patients get sequenced and researchers add fresh information to genetic databases. "That's why it's so important now to sequence tens of thousands of people and to keep track of their medical records, so we can annotate the rest of the genome," he explains. "So that five years from now when somebody else looks at their genome they won't get a little report. They'll get a much bigger report with much more statistically significant information."

Rothberg is sure that his technology will enable these massive genomic investigations that will give researchers a deeper understanding of our individual genetic destinies. But there will always be uncertainties—for most of us, the crystal ball will always be somewhat clouded. Every human being may be a unique assortment of As, Ts, Gs, and Cs, but our lives are also composed of choices: yes or no, smoking or nonsmoking, beef or tofu, stairs or elevator, live here or there, take this job or that. We're all products of both our genetic vulnerabilities and our environments, which means we have at least some control over our fates.

On my first visit to Baylor, Lupski quoted a geneticist named Leena Peltonen-Palotie to me. "I always liked her saying that our genes are the paper and pen we are born with, but the story we will write is up to us, " Lupski recalls. "Everybody makes the assumption that I'm a genetic determinist," he says. "In fact, the more you practice, the more you realize that genetics are not the whole story. They're one part of the story. We all have susceptibilities, and we can either ignore that information or maximize the utility of that information."

In other words, I can use my exome scan to write a better story of my life. Starting now. ■



PRICE PLUNGE: The decrease in production costs for sequencing a human genome (excluding all the ancillary costs of setting up a sequencing project) has easily outpaced Moore's Law. The big drop, beginning in 2008, is due to the proliferation of next-gen sequencing machines.

SOURCE FOR DATA: NATIONAL HUMAN GENOME RESEARCH INSTITUTE

上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

Faculty Positions in School of Electronic Information and Electrical Engineering (SEIEE)

The School of Electronic Information and Electrical Engineering (SEIEE) invites applications for faculty at Shanghai Jiao Tong University in the following thrust areas: *Electrical Engineering, with emphasis in smart grids* (area #1); *Control Science and Engineering* (area #2); *Electronic Engineering* (area #3); *Scientific Instruments* (area #4); and *Computer Science* (area #5). Outstanding applicants at all ranks will be considered.

Qualifications: All successful candidates must have a Ph.D. degree or equivalent in a relevant field. Candidates for regular faculty positions must provide evidences of quality teaching and outstanding research; while applicants for research-track faculty positions are expected to conduct high impact research, establish research collaborations, and supervise graduate students. Salary level will be competitive and commensurate with qualifications and experience.

Application Instructions: Submit one PDF file containing a cover letter (indicating the area of interest), the curriculum vitae, a research statement, and contact information for five references to **jobseit@sjtu.edu.cn**. Review of applications will begin immediately and continue until all positions are filled.

About SEIEE and SJTU

As the largest school at Shanghai Jiao Tong University (SJTU), the School of Electronic, Information and Electrical Engineering has 354 faculty members with considerable expertise and international recognition in seven major disciplines, including Electrical Engineering, Electronic Science and Technology, Information and Communication Engineering, Control Science and Engineering, Computer Science and Technology, Software Engineering, and Instrument Science and Technology. The school faculty has 2 members of the Chinese Academy of Science, 2 members of the Chinese Academy of Engineering, 10 IEEE Fellows, 12 Chang Jiang Scholars, 12 National 1000-Elite Scholars, 15 recipients of the National Science Foundation Distinguished Young Scholars, and 4 Chief Scientists of National "973" Project. Additional information is available at **http://english.seiee.sjtu.edu.cn**

Founded in 1896, Shanghai Jiao Tong University is a premier university in China with a century long history of excellence in research and education. Located in Shanghai, the dynamic international hub of Asia, today's SJTU has 31 schools (departments), 63 undergraduate programs, 250 masters-degree programs, 203 Ph.D. programs, 28 post-doctorate programs, and 11 state key laboratories and national engineering research centers. SJTU boasts a large number of renowned scientists and professors, including 35 academics of the Academy of Sciences and Academy of Engineering, 95 accredited professors and chair professors of the "Chang Jiang Scholars Program" and more than 2,000 professors and associate professors. Its total enrollment of students amounts to 35,929, of which 1,564 are international students.

Position of full professor (tenured) in

TU Graz
Graz University of Technology

Control Engineering and Automation

with focus on Control Engineering at Graz University of Technology/ Faculty of Electrical and Information Engineering, Institute of Automation and Control (current chair of O.Univ.-Prof. Dr.-Ing. Dourdoumas). Expected starting date 1st October 2013. Salary according to payment scheme A1 of the Austrian collective agreement for university employees, overpayment of the monthly minimum salary of the collective agreement of € 4,571.20 (14x per year) negotiable.

We are looking for a highly qualified individual with a scientific track record to actively represent the field of "Control Engineering" in research and teaching. We expect the applicant to develop an ambitious, method- and application-oriented research program in control engineering.

Graz University of Technology intends to increase the percentage of women, especially in management positions and among its scientific staff, and encourages qualified female candidates to apply. Among equally qualified applicants, women will be given priority.

Applicants are requested to submit their applications in written and electronic form no later than **2nd April 2013** (date of stamp/ e-mail receipt) to the Dean of the Faculty of Electrical Engineering and Information Technology of Graz University of Technology, Univ.-Prof. Dipl.-Ing. Mag. Dr. Heinrich Stigler, Inffeldgasse 18/EG, A-8010 Graz, E-Mail: **dekanat.etit@tugraz.at. For further information please visit us at www.e-i.tugraz.at/dekanat**

The Dean: Stigler

Joint Institute of Engineering

SUN YAT-SEN UNIVERSITY

Carnegie Mellon University

Sun Yat-sen University (SYSU) & **Carnegie Mellon University (CMU)** have established the **Joint Institute of Engineering (JIE)**, which will provide world-class education and cutting-edge research in China's Pearl-River Delta region, which provides rapidly growing opportunities for future technology innovation. JIE is seeking **full-time faculty** in all areas of Electrical/Computer Engineering. Candidates should possess a Ph.D. in ECE or related disciplines, with a demonstrated record and potential for research, teaching and leadership. The position includes an initial year on the Pittsburgh campus of CMU to establish educational and research connections before locating to **Guangzhou, China**. This is a **worldwide search** open to qualified candidates from all countries and of all nationalities, with an internationally competitive compensation package for all qualified candidates.

Faculty Positions Available *in Electrical/Computer Engineering*

Visit **http://sysucmuji.cmu.edu** *for details.*

NAZARBAYEV UNIVERSITY

Faculty positions: Robotics and Computer Science
School of Science and Technology
Nazarbayev University
Astana, Kazakhstan

Nazarbayev University is seeking highly-qualified faculty at all ranks (assistant, associate, full professor) to join its rapidly growing undergraduate and graduate programs in the School of Science & Technology. NU was launched in 2010 as the premier national university of Kazakhstan, based on the Western model, with English-language instruction, partnering with some of the most recognized international universities including University of Cambridge, Carnegie Mellon University, University of Wisconsin, University College London, University of Pennsylvania, University of Pittsburgh, and Duke University.

Full-time faculty positions are open in the Departments of Robotics and Computer Science. Successful candidates must have an earned Ph.D. degree from an accredited university, excellent English-language communication skills, a demonstrated ability for research, and a commitment to graduate and undergraduate teaching.

Position responsibilities include: a teaching load of two courses (on average) per semester, establishment of an independent research program, program guidance and leadership (for senior positions), student advising and supervision, and general service to the department and the university.

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

To Apply: applicants should send a detailed CV, including qualifications, experience, and list of publications to sst@nu.edu.kz. Interested parties are encouraged to submit their applications no later than **May 15th 2013.** Application Information: Please forward your curriculum vitae to **sst@nu.edu.kz. Additional information** can be found on our website **(www.nu.edu.kz). Contact:** Ronald Bulbulian Ph. D. FACSM, Dean, School of Science & Technology.

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

FACULTY POSITION: DIRECTOR OF GEOMETRIC MODELING AND SCIENTIFIC VISUALIZATION CENTER

The Geometric Modeling and Scientific Visualization Center (GMSV) (http://gmsv.kaust.edu.sa) at King Abdullah University of Science and Technology (KAUST) is seeking a leading scientist in visual computing as Director. The Center is part of the Computer, Electrical, and Mathematical Sciences and Engineering (CEMSE) Division, and the associated faculty appointment will be for Full Professor either in Computer Science or Applied Mathematics.

The Director manages an interdisciplinary center with a multi-million dollar annual portfolio whose members have dedicated extraordinary research facilities for simulation, visualization and immersive environments, generous research space, and stable funding to support the Director, faculty, postdocs, and graduate students. In terms of facilities, the center has prime access to the CORNEA Visualization center and the university has a related supercomputer (Shaheen). The successful candidate will be an internationally recognized leader in visual computing. The center has a research portfolio in areas such as computer graphics, computational design, computer vision, image processing, data visualization, data analysis and understanding, and high-performance scientific visualization. With currently 65 members, it is still undergoing significant growth and has exceptional opportunities through multi-disciplinary interactions with other KAUST research thrusts in extreme scale computing, computational biology, materials science, marine sciences, water desalination, and solar energy, to name a few.

All candidates should have the ability to pursue a high impact research program and have a commitment to teaching at the graduate level. Applicants should apply at **http://apptrkr.com/316434** . Applications received by March 31, 2013 will receive full consideration and the position will remain open until filled.

King Abdullah University of Science and Technology (KAUST) is an international, graduate research university dedicated to advancing science and technology through interdisciplinary research, education, and innovation. Located on the shores of the Red Sea in Saudi Arabia, KAUST offers superb research facilities, and internationally competitive salaries. The university attracts top international faculty, scientists, engineers, and students to conduct fundamental and goal-oriented research to address the world's pressing scientific and technological challenges related to the sustainability of water, food, energy, and the environment.

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

The Hong Kong Polytechnic University is a government-funded tertiary institution in Hong Kong. It offers programmes at various levels including Doctorate, Master's, and Bachelor's degrees. It has a full-time academic staff strength of around 1,200. The total consolidated expenditure budget of the University is close to HK$5 billion per year.

DEPARTMENT OF ELECTRICAL ENGINEERING

1) Professor / Associate Professor / Assistant Professor in Energy and Power Systems / Asset Management and Transportation Systems Engineering / Utilisation and Power Electronics (two posts)

2) Associate Professor / Assistant Professor in Asset Management and Transportation Systems Engineering / Utilisation and Power Electronics / Underpinning Key Technologies including Photonics, Smart Materials, Computing and Control (two posts)

The Department of Electrical Engineering is one of the six academic units in the Faculty of Engineering. It is the major education provider in electric power engineering and utilisation of electric power among the universities in Hong Kong. The Department is playing an important role in educating the electrical engineers for Hong Kong, and to some extent for the Chinese mainland arising from its continuous expansion in the electrical infrastructure. Please visit the website at http://www.ee.polyu.edu.hk for more information about the Department. The post specification of this position can be obtained from http://www.polyu.edu.hk/hro/job_external.htm#acad.

A highly competitive remuneration package will be offered. Initial appointment for Assistant Professor will be on a fixed-term gratuity-bearing contract. Re-engagement thereafter is subject to mutual agreement. An appropriate term will be provided for appointment at Associate Professor and Professor levels. Applicants should state their current and expected salary in the application.

Application
Please submit application form via email to hrstaff@polyu.edu.hk; by fax at (852) 2364 2166; or by mail to **Human Resources Office, 13/F, Li Ka Shing Tower, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.** If you would like to provide a separate curriculum vitae, please still complete the application form which will help speed up the recruitment process. Application forms can be obtained via the above channels or downloaded from http://www.polyu.edu.hk/hro/job.htm. **Recruitment will continue until the positions are filled**. Details of the University's Personal Information Collection Statement for recruitment can be found at http://www.polyu.edu.hk/hro/jobpics.htm.

For further details about the University, please visit **www.polyu.edu.hk**

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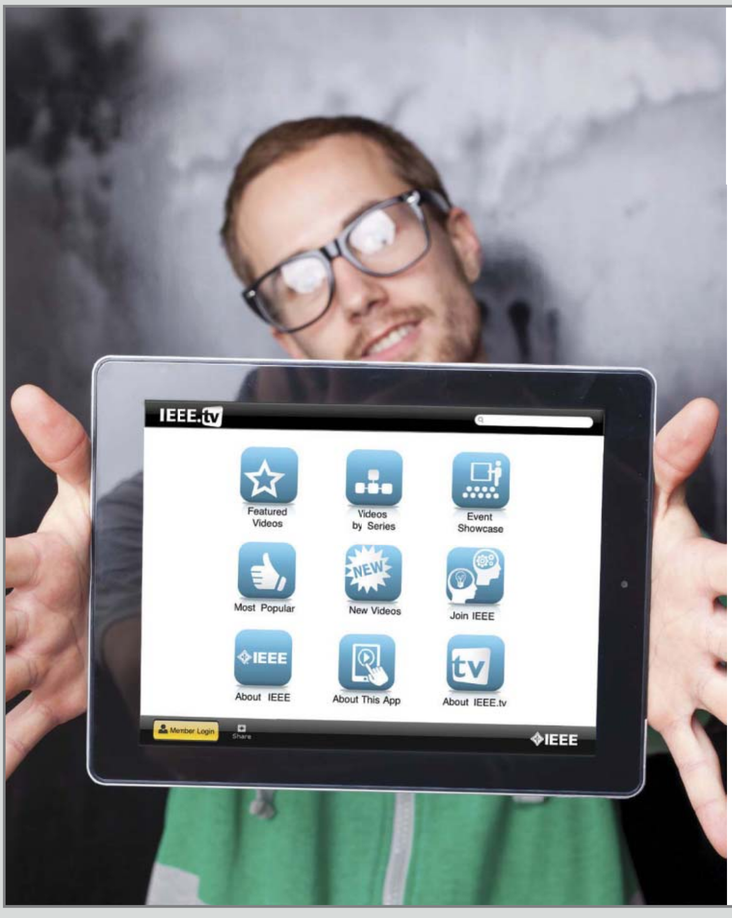

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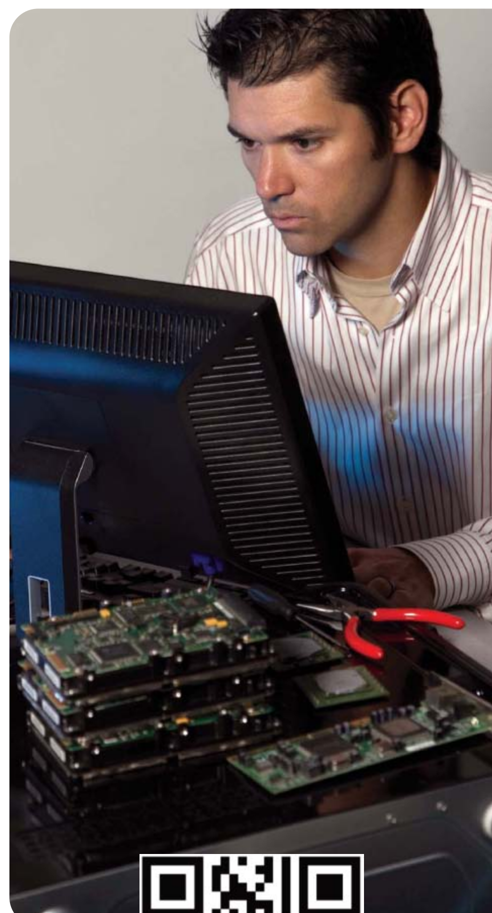

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DATAFLOW_

CONSUMER ELECTRONICS WINNERS AND LOSERS

TABLETS WERE THE BRIGHTEST SPOT IN SALES FOR THE U.S. 2012 HOLIDAY SEASON

Before the 2012 make-or-break U.S. holiday buying season (which this year ran from 23 November to 24 December), the Consumer Electronics Association (CEA) estimated that spending on consumer electronics would increase a few percentage points. Unfortunately for manufacturers and retailers, an analysis released in January by the CEA showed that actual spending was flat. But that overall figure conceals that some categories are booming while others are in decline. —STEPHEN CASS

Key | Projected Sales | Actual Sales Winner | Actual Sales Loser

Expectations vs. Reality

(millions of units sold)

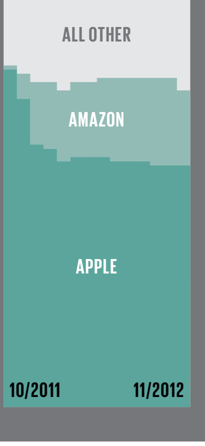
1 Video-Game Consoles
With no new consoles on the horizon from the big three—Sony, Microsoft, and Nintendo—sales are expected to continue to fall in 2013.

2 Tablets
Despite the presence of major manufacturers like Samsung in the tablet market, Apple and Amazon still accounted for 76 percent of sales.

3 Digital Cameras
While point-and-shoot digital camera sales appear to be suffering due to the availability of built-in cameras on smartphones, more-sophisticated cameras beat expectations.

Tablet Market Share

(12-month rolling average)



SOURCES: CONSUMER ELECTRONICS ASSOCIATION (SALES); NPD GROUP/CONSUMER TRACKING SERVICE (MARKET SHARE)

INFOGRAPHIC BY Carl De Torres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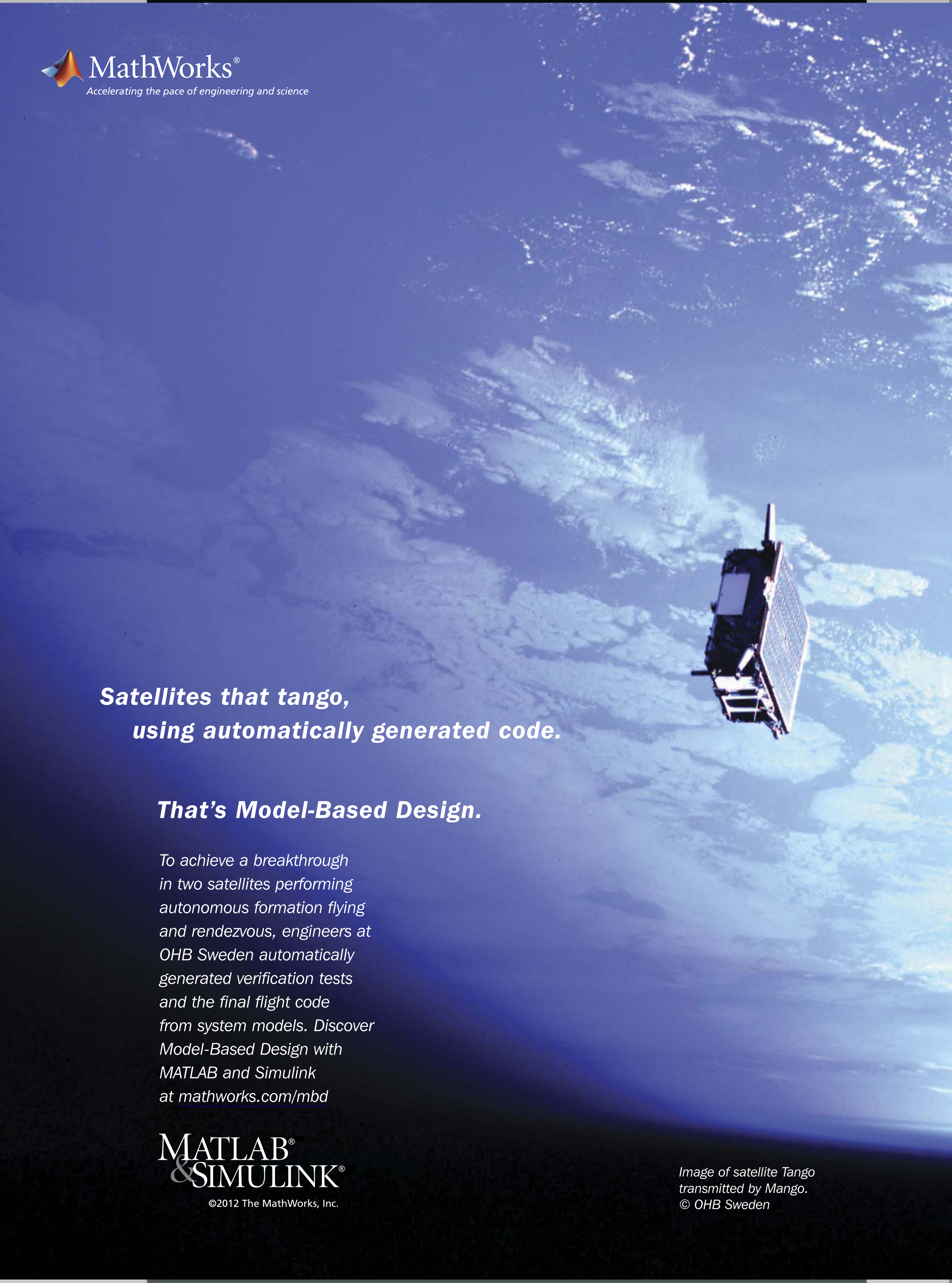
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