IEEE Spectrum
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SHADES OF THE SINGULARITY

RAY KURZWEIL'S FUTURE IMPERFECT

BY JOHN RENNIE

THINKING LIKE A HUMAN—WITH MEMRISTORS

BY MASSIMILIANO VERSACE & BEN CHANDLER

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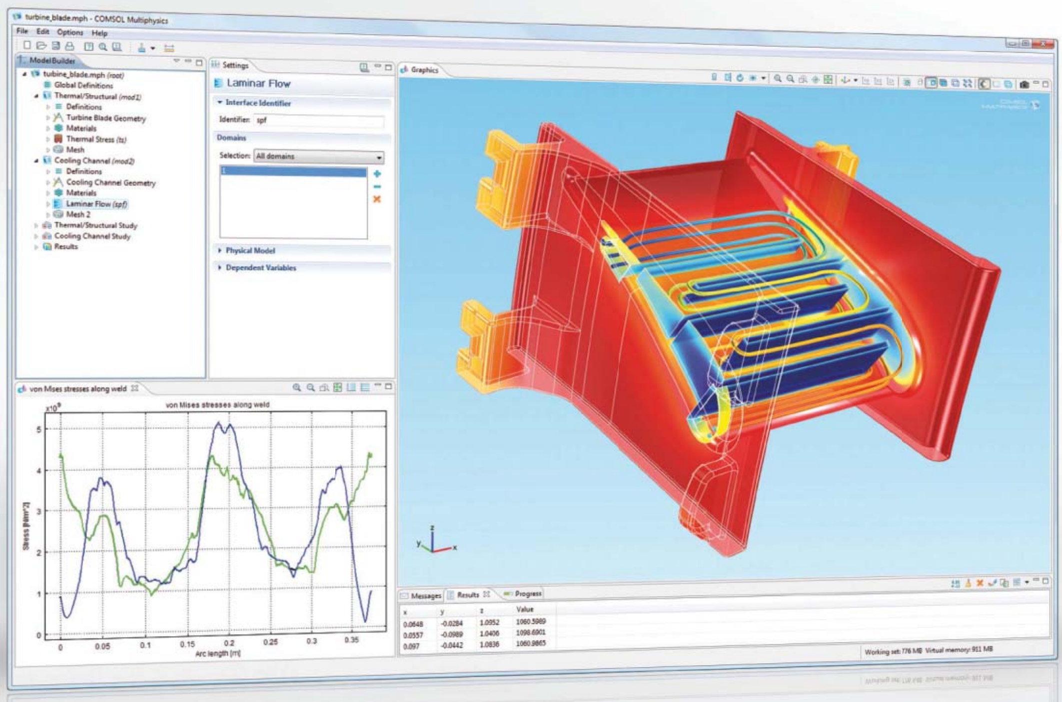

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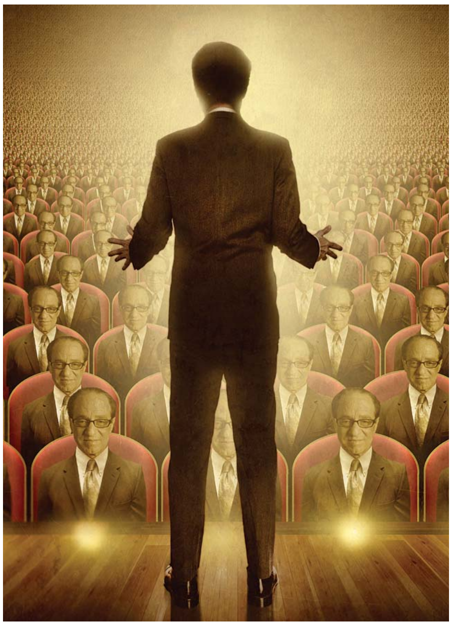

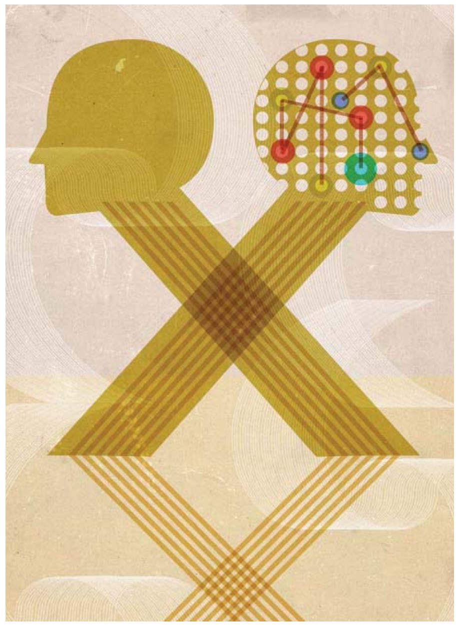

Shades of the Singularity

COVER: BRAIN IMAGE: ISTOCKPHOTO; PHOTO-ILLUSTRATION: MARK MONTGOMERY THIS PAGE, CLOCKWISE FROM TOP LEFT: MATT MAHURIN, CHAD HAGEN, EFE/EL PAIS/AP PHOTO, DAN SAELINGER

UPDATE

OPINION

DEPARTMENTS

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Resurrecting Tempest

Arcade games don't get much cooler than Atari's Tempest, released in 1981. Tempest's angular cabinet, spinner knob control, and fast-paced 3-D action set it apart. Little wonder then that contributing editor and game freak David Kushner volunteered to fix his neighbor's dead Tempest machine. Join him on his quest to resurrect a machine abused by time and one very unlucky mouse.

THE FIFTH ESTATE

LIKE THE CLERGY, nobility, commoners, and the press, engineers and scientists constitute an estate of their own, says G. Pascal Zachary in his new series for *IEEE Spectrum*, The Scientific Estate. Every month he explores how technoscientists interact with society to determine what research gets funded, what technologies emerge into the market, and what kinds of jobs engineers will be taking on in the years to come.

JOIN THE CONVERSATION

OUR NEW COMMENTING system should make it easier to share your opinions. Enhancements include social network integration, threaded discussions, and formatting flexibility.

TOP: RANDI SILBERMAN KLETT; BOTTOM: JAMES PROVOST

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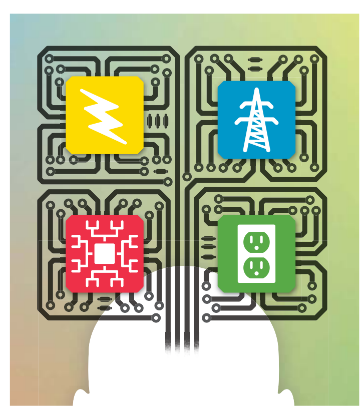

SMART GRID SHOWCASE
Read about IEEE's involvement in building the smart grid in this month's special issue on the topic. Articles cover IEEE's work in many aspects of modernizing the grid, including standards, continuing education, conferences, and publications.

ELECTION RESULTS
The votes are in for the 2010 annual IEEE election. Find out who was chosen 2011 IEEE president-elect.

PART-TIME PASSIONS
When they're not busy with work, IEEE members are involved with some interesting hobbies. A Life Fellow in Brookhaven, N.Y., sails around the world, and a member in Kewaunee, Wis., plays disc golf.

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back story

The Cat and the Computer

WHAT IS it about cats—or in this case, their brains—that can make otherwise rational people act goofy?

A year ago, *IEEE Spectrum* reported that IBM had won a major computing award for simulating the neurons and synapses in the brain of a cat. When the news broke, initial coverage of the award morphed, as if by a game of telephone, into reports that IBM had managed to simulate an entire cat brain.

Bedlam ensued. A normally mild-mannered scientist who had simulated a small area of the brain of a rat called for the award-winning IBM researcher to be "strung up by his toes." The forums of *Spectrum* and other relevant sci-tech magazines soon filled with invective and accusations that the entire field of computational neuroscience was a shameful hoax.

The hysteria was a symptom of a larger problem in a field whose goal is to create computer software that approximates the functions of the mammalian brain. Because no one agrees on exactly how intelligence arises in people, it's impossible to know which approach to building it into machines is correct, which approach is barking (or meowing) up the wrong tree, and which is just barking mad.

Into the fray stepped Massimiliano Versace and Ben Chandler [above, center and right], two Boston University computer scientists. Their incisive, repeated commentary on *Spectrum's* online forum prompted Associate Editor Sally Adee [left] to contact them. They became the sources for a postmortem article, published on IEEE Spectrum Online two months later, that became the foundation of the Wikipedia entry on cat intelligence.

Versace and Chandler are working with HP Labs (the creators of the first usable memristor) and the U.S. Department of Defense on a project to create truly intelligent machines. But they wisely decline to say whether they expect their artificial intelligence to be in rat or cat form. They describe their pathbreaking work in this month's "Brain of a New Machine." ❑

CITING ARTICLES IN IEEE SPECTRUM

IEEE Spectrum publishes two editions. In the international edition, the abbreviation INT appears at the foot of each page. The North American edition is identified with the letters NA. Both have the same editorial content, but because of differences in advertising, page numbers may differ. In citations, you should include the issue designation. For example, Technically Speaking is in *IEEE Spectrum,* Vol. 47, no. 12 (INT), December 2010, p. 21, or in *IEEE Spectrum*, Vol. 47, no. 12 (NA), December 2010, p. 23.

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AT THE FRONTIERS OF SIMULATION
CST STUDIO SUITE
2011

contributors

SETH BLUMSACK, an economist in the College of Engineering at Pennsylvania State University, says of his colleagues, "Engineers have this idea that economics is about money." But he warns them "not to depend on him for stock tips." He does have lots to say, though, on electricity economics (as a part of the Penn State Electricity Markets Initiative), which he shares in "How the Free Market Rocked the Grid" [p. 42].

MARK HARRIS is a British technology and lifestyle reporter based in Seattle. Although wowed by 3-D View-Masters as a child, he credits the 1953 classic *House of Wax*, starring Vincent Price, for triggering a lifelong fear of 3-D glasses (and of Madame Tussauds). It took interacting with the latest glasses-free gadgets in "3-D Without Four Eyes" [p. 48] to finally cure his phobia. He writes regularly for *The Sunday Times*, *The Economist*, and *Wired UK*.

MATT MAHURIN, who illustrated "Ray Kurzweil's Slippery Futurism" [p. 22], says, "I have based my entire career on taking risks." Known for his controversial 1994 *Time* cover, a darkened mug shot of O.J. Simpson, Mahurin is proudest of his first *Time* assignment, 11 years earlier. Asked for two illustrations on domestic violence, he submitted 10 choices, some uncharacteristically graphic for the newsweekly. *Time* ran them all. He was later forwarded a pile of letters from rape victims thanking him for making an emotional connection.

HENRY PETROSKI, a professor of engineering and history at Duke University, is the author of 14 books and numerous articles. His most recent book is *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems* (Knopf, 2010), a subject he revisits in this month's Spectral Lines [p. 8]. Petroski is a member of the U.S. Nuclear Waste Technical Review Board and the recipient of many honors, including a Guggenheim Fellowship.

JOHN RENNIE, author of the feature on Ray Kurzweil's record as a prognosticator [p. 22], was the editor in chief of *Scientific American* from 1994 to 2009. He now writes, blogs (The Gleaming Retort, http://blogs.plos.org/retort), and teaches journalism at New York University. He lives in New York City with his Emmy-winning video editor wife and their "swell dog," Newman. He is an occasional television commentator and a black belt in Kenshikai Karate, which is "a small Japanese style that none of your readers will have heard of."

SARGUR N. SRIHARI, author of "Computing the Scene of a Crime" [p. 36], is an IEEE Fellow and a professor at the State University of New York at Buffalo. Compiling large sets of forensics data can be costly and time-consuming, but he's learned to be resourceful. One unexpected source: the footwear purveyor Zappos.com, which offers detailed photos online of each shoe it sells, including the sole. "You'd think most people wouldn't be interested in that level of detail," Srihari observes. "But it's a very nice database for researchers like me."

CLOCKWISE FROM TOP RIGHT: U.S. NUCLEAR WASTE TECHNICAL REVIEW BOARD; SPENCER HEYFRON; STATE UNIVERSITY OF NEW YORK AT BUFFALO; MATT MAHURIN; JOHN BENTON-HARRIS; PENNSYLVANIA STATE UNIVERSITY

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spectral lines

HARRY CAMPBELL

Engineering ≠ Science

IN POLITICAL discourse, public policy debates, and the mass media, *engineering* is often a synonym for *science*. This confusion might seem an innocuous shorthand for headline writers, but it can leave politicians, policymakers, and the general public unable to make informed decisions about the technical challenges facing the world today.

Science is about understanding the origins, nature, and behavior of the universe and all it contains; engineering is about solving problems by rearranging the stuff of the world to make new things. Conflating these separate objectives leads to uninformed opinions, which in turn can delay or misdirect management, effort, and resources.

Take this year's oil spill in the Gulf of Mexico. No one, to the best of my knowledge, blamed it on science. Poor engineering decisions allowed gas to escape from a well in deep water, which in turn caused a fatal explosion. Subsequently, the engineered blowout preventer failed, and for months oil escaped into the environment. Poor engineering got us into the mess; surely only good engineering could get us out of it. Yet repeatedly, government and other research scientists were allowed to veto the engineering tactics needed to stanch the flow. In the end, of course, it was engineering that finally capped the well.

While not all of the technological challenges facing the world today require the same immediate attention as a gushing oil well—some are as mundane as developing renewable energy sources, providing clean water, and disposing of our mountains of garbage—they still present the same duality.

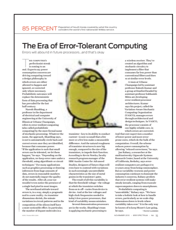
Scientists might argue that the government needs to invest in basic scientific research that will lead to unspecified discoveries about energy, water, and waste. Although a good deal is already known about those things, it certainly would not hurt to know more, but what would really move things forward would be investments in engineering.

Throughout history, a full scientific understanding has been neither necessary nor sufficient for great technological advances: The era of the steam engine, notably, was well into its second century before a fully formed science of thermodynamics had been developed. Indeed, sometimes science has impeded progress. Had Marconi believed his physicist contemporaries, he would have "known" that wireless telegraphy signals could not be sent across the ocean, around Earth's curvature.

Engineers welcome any and all available scientific knowledge, but they needn't wait for scientists to give them the go-ahead to invent, design, or develop the machinery to advance technology or to check it when it runs out of control. Without understanding this, we will continue to underfund the engineering needed to solve our greatest problems.

—HENRY PETROSKI

Henry Petroski is the Aleksandar S. Vesic Professor of Civil Engineering and a professor of history at Duke University.

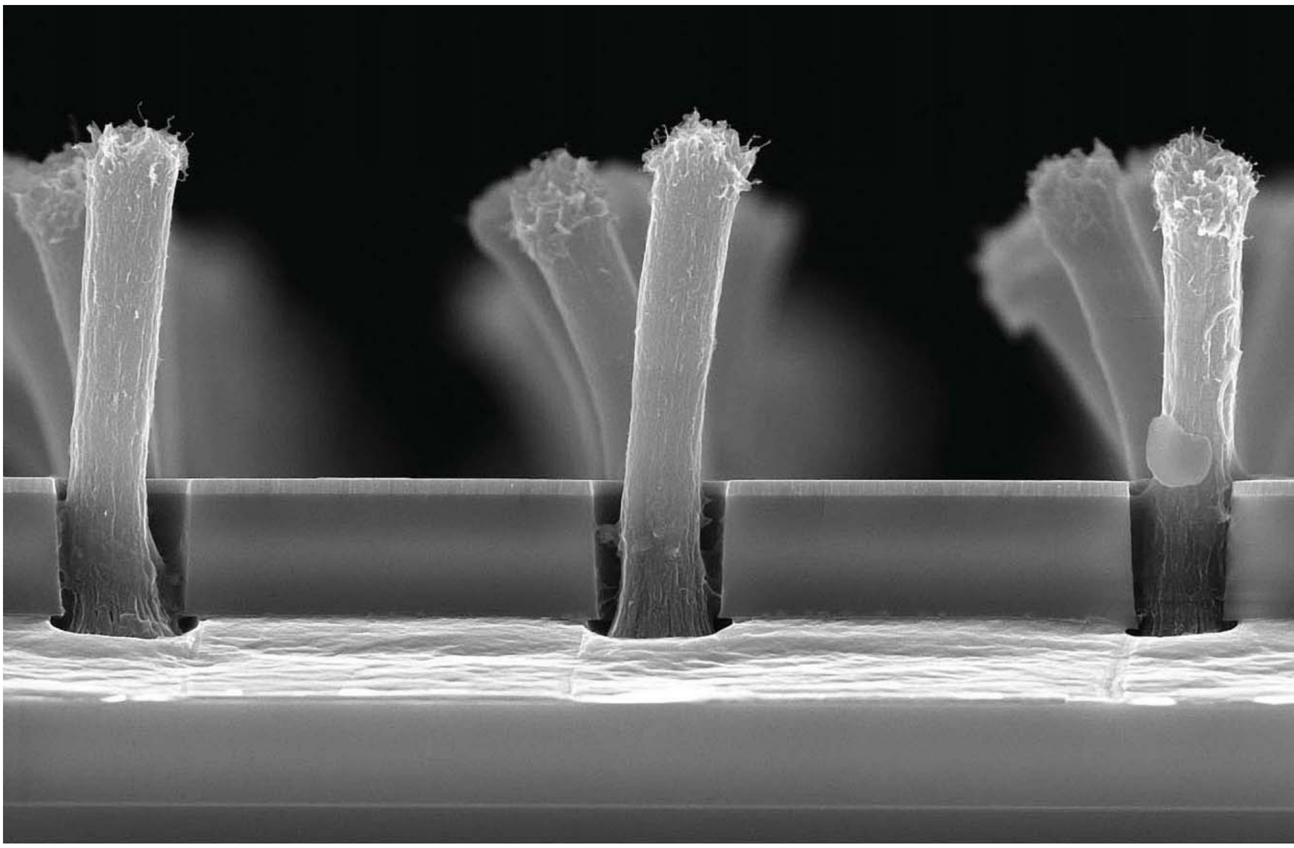


Correction

In "The Era of Error-Tolerant Computing" [Update, November], we incorrectly described the nature of the VASCO processor cores. For a more accurate description of VASCO, please see the article at http://spectrum.ieee.org/errortolerant1110.

update

more online at spectrum.ieee.org



Can Carbon Put Copper Down for the Count?

In the nano realm, copper vertical interconnects won't cut it

COPPER INTERCONNECTS carry current in today's integrated circuits, but in the nanometer-size future, the metal just won't do the job. At this month's 2010 International Electron Devices Meeting, in San Francisco, European researchers plan to announce that they're one step closer to a replacement. Nanotubes made of carbon, if grown in dense bundles, can transport large quantities of charge through tiny channels reliably. As part of the European ViaCarbon project, a team led by Jean Dijon, the head of nanotube research at the French government research organization CEA LITEN in Grenoble, says they've grown the densest bundles yet, packing 2.5 trillion carbon nanotubes per square centimeter. The density of their interconnects is within an order of magnitude of what's needed for replacing copper. In the future, such bundles have the potential to exceed copper's current-carrying capabilities by a factor of 100.

Copper needs a replacement particularly in the narrow pegs, called vias, that connect the silicon surface to the chips' wiring and connect one layer of wiring to another. According to the 2009 International Technology Roadmap for Semiconductors, engineers predict that as the features on chips shrink, not only will copper vias be more difficult to manufacture and suffer from more resistance, but by 2015 they may not work at all.

Vias start as holes etched into a layer of dielectric. Depositing

PACKED PILLARS: Dense bundles of nanotubes erupt from a metal surface. They could replace copper as vertical interconnects on future chips.
IMAGE: JEAN DIJON

update

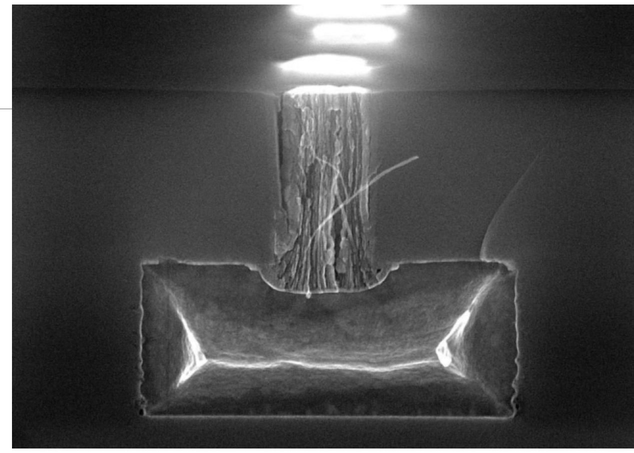
copper ions from an electrolyte fills the holes, but at the nanometer scale, the metal could cling to the walls, leaving gaps. Also, the vias' walls must be lined with a metal nitride barrier to keep copper from seeping into the surrounding dielectric. The liner wastes space and increases resistance.

Engineers are also concerned that copper vias will prove unreliable at future nanometer-scale dimensions. Skinnier copper means that current density and resistivity both increase. Together, those factors cause the interconnects to heat up and break. "For each new generation, as dimensions decrease, current densities increase and will soon approach the copper limit," says Murielle Fayolle-Lecocq, a microelectronics engineer who worked on the new nanotube vias at France's CEA-LETI.

Carbon nanotubes have the perfect shape for fitting into future vias' voids: "Naturally, they're tall and thin," says the leader of the ViaCarbon project, John Robertson, who is an electrical engineering professor at the University of Cambridge, in England.

The team's goal was to grow dense bundles of narrow nanotubes. Although nanotubes are usually championed for their ability to carry charge long distances with little resistance, quantum interactions in individual nanotubes can actually give them more resistance than the copper interconnects they're meant to replace.

Bundles of parallel nanotubes can solve that problem by providing multiple channels for electricity to flow. That lowers the nanotubes' effective resistance, making them seem like many individual resistors connected in parallel, says Robertson. Using nanotubes with only a few layers and carefully selecting the material on which they



BIG BUNDLE: Nanotubes are tightly bound to increase conductivity.
IMAGE: JEAN DIJON

grow will ensure that the tubes have a small diameter and thus increase the possible bundle density.

If packed densely enough, these bundles can carry about 1 billion amperes per square centimeter, around 100 times copper's limit. But they haven't reached that ideal yet. Although the team has packed the tubes 10 times as densely as others, Robertson says, to match copper's conductivity they will need to increase the density by another factor of 10, to around 30 trillion nanotubes per square centimeter.

Adrian Ionescu, head of the Nanolab at École Polytechnique Fédérale de Lausanne and a contributor to the nanotube via project, adds that the team will need to improve the tubes' contact with the metal horizontal interconnects in integrated circuits. Ionescu believes that in the future, nanotubes—or a combination of nanotubes and graphene sheets—could replace the copper in even these horizontal interconnects.

"They still have to increase the density by quite a bit," says Kaustav Banerjee, director of the Nanoelectronics Research Lab at the University of California, Santa Barbara, who was not involved in the research. But, he adds, "this is definitely a significant improvement and very positive news." —Joseph Calamia

To comment on this or other stories, please visit http://spectrum.ieee.org.

GAMING THE SYSTEM

IEEE Spectrum's experiment in crowdsourcing used a game to guess the future of water and energy

The relationship between water and energy is massively complex. So how do you untangle such a knotty problem? With a massively multiplayer online game, of course!

On 3 June, the editors of *IEEE Spectrum* brought together 1338 engineers, scientists, and students from 88 countries to brainstorm how the issues covered in our June special report, "Water vs. Energy," might play out. Think of it as crowdsourcing today's toughest challenges.

We partnered with the Institute for the Future, a forecasting research center in Palo Alto, Calif., which provided the gaming platform. According to Jane McGonigal, the institute's director of game research and development, the online platform "allows people to very playfully imagine the scientific future." In the game, 248 players submitted short predictions about how water and energy resources will compete in the future. With each new prediction, other players parried with their own microforecasts, fleshing out the consequences of each move.

The participants, drawn heavily from Australia, Canada, India, New Zealand, and the United States, brought up many ideas seen regularly in these pages. Some players suggested sweeping measures, including introducing a global water tax or building an intercontinental electrical supergrid. Other participants proposed farming biofuel algae in salt- and wastewater and designing industrial ecologies so that the waste of one industry serves as the feedstock for another.

The game was an experiment in extending the conversation that begins each month in this magazine and every day on our Web site. The encouraging feedback we've received has inspired us to organize another game, in which we hope you'll help us tackle the promise and pitfalls of the smart grid.

For more on the game's results, go to http://spectrum.ieee.org/waterpodcast0610.

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116 Mobile phone subscribers per 100 inhabitants in the developed world, according to the International Telecommunications Union

SUNROOF: Clif Bar & Co.'s rooftop solar array is smarter than average.

PHOTO: TIGO ENERGY

Smarts for Solar Arrays

Start-ups are vying to squeeze more energy out of solar panels, with distributed intelligence

MORE THAN a dozen venture-capital-backed start-ups are vying to bring some smarts to solar farms in the hope of boosting photovoltaic arrays' ability to deliver carbon-free energy. The offering by Tigo Energy, based in Los Gatos, Calif., may be the simplest and most cost-effective of these distributed intelligence schemes. The three-year-old firm is exploiting wireless communications to minimize the added cost and complexity of PV arrays' energy-harvesting electronics, an approach that could quickly win over risk-averse system installers.

Tigo's strategy is getting its highest-profile test at the El Cerrito, Calif., headquarters of sports foods producer Clif Bar & Co. Solar installer Sun Light & Power, of Berkeley, Calif., is festooning Clif Bar's carport and rooftops with nearly 2000 silicon solar panels. Sun Light & Power is betting that by individually monitoring, controlling, and optimizing each panel, Tigo's system will squeeze 6 to 8 percent more energy from the 530-kilowatt array.

Such potential exists thanks to the inherent inefficiencies in the way PV arrays are designed today: The panels blindly feed their direct current to a centralized inverter. The inverter turns the array's DC into AC in sync with the power grid, but it must also maximize the DC flow coming in by controlling the entire array's impedance.

Centralized impedance control wastes energy, because a PV array's panels are rarely uniform. Variable shading from trees, buildings, or shifting clouds turns PV arrays into an electrical mosaic. The problem only gets worse with age as panels degrade at varying rates from their factory-shipped specs. The centralized inverter must pander to its array's lowest common denominator, setting an impedance that maximizes the panel's harvest of charges generated on the lowest-performing panels. Extra charge generated by overachieving panels is left to recombine and dissipate as heat.

The early market leader among the firms addressing PV's "module mismatch" problem, Enphase Energy, proposes to replace the big centralized inverter with microinverters attached to each panel. But in doing so, it may have limited its potential market. Electronics market consultancy IMS Research concluded this August that the microinverters' higher cost would preclude their use in utility-scale solar plants.

Gary Gerber, Sun Light & Power's president, says he is concerned about failure-prone components in microinverters such as liquid-filled capacitors, which add reliability risk to rooftop installations. "You put thousands of those out on roofs and they start failing, and you have a lot of work to do to repair and replace units, especially in residential installations where the panels are generally flush to a roof," says Gerber, a past president of the California Solar Energy Industries Association, which represents many installers.

Tigo's approach should be fairly fail-safe because

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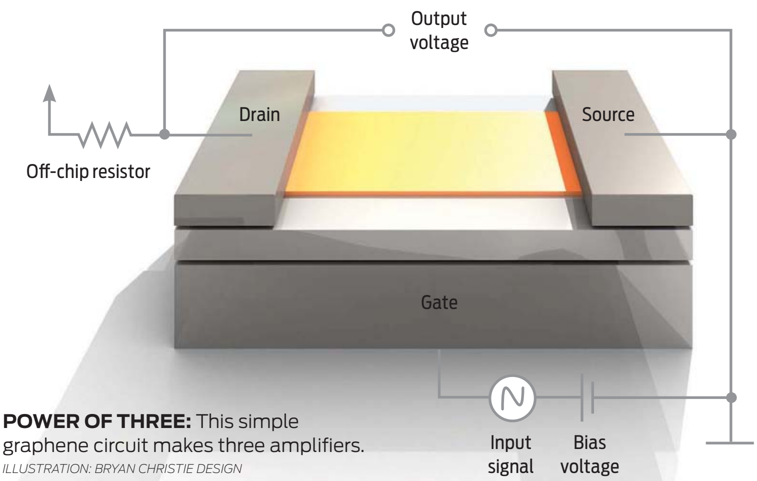
its distributed electronic devices are comparatively simple. The modules attached to each solar panel contain a basic circuit that modifies impedance and a 2.4-gigahertz wireless interface; all processing capabilities reside in a centralized management unit. In operation, Tigo's modules transmit a power reading every 3 seconds, the central unit crunches the data to calculate the optimum impedance for each panel, and those marching orders are transmitted back to the modules.

The result is that each panel is assured to generate maximum DC power, leaving the centralized inverter to concentrate on its forte: efficiently churning out synchronous AC. Gerber says Tigo's hardware is edging up Clif Bar's PV price tag by roughly 4.5 percent, but he predicts that increased energy flow when the array starts up later this winter will more than pay back the added costs, boosting Clif Bar's overall return on investment.

Profit margins should increase as Tigo works with PV manufacturers to build its system into PV panel junction boxes at the factory. Several leading PV manufacturers have announced plans to integrate Tigo's circuitry, including Schott Solar, Solyndra, and Suntech Power. Tigo vice president Jeff Krisa says those partnerships should beget several Tigo-optimized solar projects at the 10- to 20-megawatt scale by the end of 2011. Gerber says it could become mainstream practice within three to four years.

Gerber points to one more benefit that has less to do with dollars and cents and more with organizations like Clif Bar wearing their green credentials: The data flowing into Tigo's central management units is easily output to the Internet, to be incorporated in Web sites or in-building displays that lay open an array's output in real time. "I can't overemphasize the value of the display technology," says Gerber. "That's a huge PR benefit."

—Peter Fairley



POWER OF THREE: This simple graphene circuit makes three amplifiers.
ILLUSTRATION: BRYAN CHRISTIE DESIGN

One Graphene Device Makes Three Amplifiers

Logic device could be even more multipurpose

Graphene devices are showing amazing flexibility, and not just the mechanical kind. Researchers at Rice University and the University of California, Riverside, recently demonstrated an amplifier, based on a single graphene transistor, that can do the job of three different amplifiers. The device could lead to smaller, lower-power analog circuits, such as Bluetooth radios, they say. Separately, scientists at IBM are developing a type of graphene device that can be reconfigured, on the fly, into six different logic gates. Despite this, engineers agree that practical graphene logic is many years away.

Graphene has many remarkable qualities, which its proponents say could make it a successor to silicon as a basis for electronics. One promising property is that it's ambipolar—both electrons and holes, positive charge carriers in semiconductors, can carry current through the material, and the application of voltage can control the contributions of the two types of carriers to the current through a device. This property enables a single graphene-based amplifier to act as more than one type of amplifier or potentially as a variety of logic gates.

"There's a growing consensus that people should consider ambipolarity a little more seriously," says Kartik Mohanram, an assistant professor of electrical engineering at Rice, in Houston.

Mohanram and his colleagues set about building the amplifiers using a single graphene transistor. In conventional complementary metal-oxide semiconductor (CMOS) circuits, the type of amplifier is determined by how it's built, and it can't be changed later. But thanks to ambipolarity, a graphene-based amplifier can switch types just by adjusting a voltage.

Depending on whether electrons or holes dominate the current, you get an *n*-type or a *p*-type field-effect transistor. The hole-rich *p*-type acts as a straightforward amplifier; the electron-rich *n*-type shifts the signal's phase by 180 degrees. If the flow of negative and positive carriers is equal, the transistor becomes a frequency multiplier. Switching signals in the device between two phases (phase-shift keying) or two frequencies (frequency-shift keying) allowed the team to encode digital data onto an RF signal.

Mohanram and his colleagues, aided by Alexander Balandin from

“Metal is the old way. Metal is stupid”

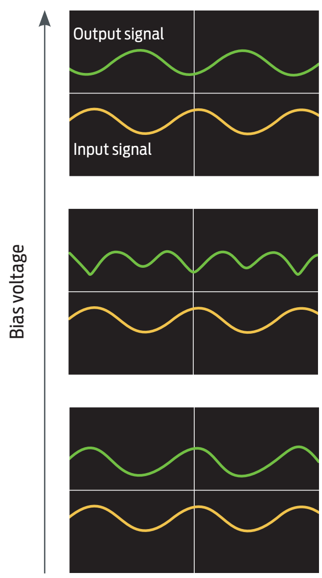
Masayoshi Son, chairman and CEO of the Tokyo-based telecom and media company SoftBank Mobile Corp. Son challenged the Japanese government to back his plan for converting all of Japan’s telecom lines to optical fiber.

the University of California, Riverside, published their proof-of-concept demonstration in *ACS Nano* in October.

“What we were excited about was we could do phase-shift keying and frequency-shift keying with a single transistor,” says Mohanram. A CMOS-based amplifier might require six transistors for the same functions, he says. Additionally, graphene circuits could handle much higher frequencies than their silicon counterparts. Engineers at IBM and the University of California, Los Angeles, have demonstrated graphene transistors with the potential for terahertz speeds. Silicon circuits, on the other hand, typically max out in the tens-of-gigahertz range.

IBM, too, is working on a graphene-based amplifier and radio-frequency transistor, part of a program funded by the Defense Advanced Research Projects Agency. Chun-Yung Sung, program manager for graphene nanoelectronics at IBM’s Thomas J. Watson Research Center, in Yorktown Heights, N.Y., says he expects prototypes in about five years. The development of thin-film graphene could lead to flexible, printable circuits that can be reconfigured at will, Sung says.

While analog devices based on graphene may be just a few years in the future, the path to replacing silicon circuits with graphene-based logic remains a long one, says Mohanram.



ABOUT PHASE: Boosting the bias voltage changes the amplifier’s output.

That’s because graphene naturally lacks a band gap, the property of semiconductors that controls the operation of transistors and other devices. One solution may be to sculpt the graphene into nanoribbons just a few nanometers wide, essentially squeezing the electric field within the material to produce a band gap [see “Graphene Electronics, Unzipped,” *IEEE Spectrum*, November 2010].

Logic based on graphene will have to be built on a new concept, one that takes advantage of the material’s unique properties, says Sung. Sung and his colleagues propose making a *p-n* junction out of sheets of graphene and applying positive or negative voltages to switch the electronic state of the material, providing an on-off switch. Depending on the voltages it is subject to, this device could switch between being a NOT gate, an OR gate, or an AND gate, among other functions.

“These revolutionary devices will come with revolutionary architecture,” Sung says. And as CMOS shrinks closer to the point where it can’t get any smaller—about 10 nanometers is expected—coming up with those architectures becomes more urgent. “We need to come up with device options before 2020,” he says. —Neil Savage

news brief

Nuclear Fingerprints: Scientists at the U.S. National Institute of Standards and Technology have used careful analysis of glasslike material found in the New Mexico desert to reconstruct the inner workings of the first nuclear bomb. Unlike in earlier examinations, they were able to identify the origins not just of the fissile material used in the bomb but also the structural material, known as the tamper. Their methods could help pinpoint the country of origin of nuclear weapons even after they’re detonated.

PHOTO: ATOMIC ARCHIVE

Landslide Alarm

A new acoustic sensor can hear when a landslide is imminent

Just after midnight on 8 August, a massive landslide sent nearly 2 million cubic meters of rock and mud hurtling through several towns in Zhouqu County, China. The natural disaster killed more than 1500 people in the county, which sits in a valley between two mountains in Gansu Province. Three months later, more than 250 people were still unaccounted for.

Though their breakthrough is too late for the Zhouqu disaster, researchers at Loughborough University, in England, reported in October that they have developed an electronic system that can warn of an impending landslide by picking up the telltale sounds of shifting earth.

Engineering geologists have known for decades that in the buildup to a landslide there is barely perceptible movement (on the order of about a millimeter a day) along an underground plane known as the shear surface. The shear surface controls the volume of the landslide and the speed at which a chunk of earth can move down a slope. Scientists also know that it’s possible to predict a landslide by checking for sounds made by particles rubbing against one another at the shear surface. The problem, says Neil Dixon, a professor of geotechnical engineering at Loughborough, is that the sound is quite faint and attenuates rapidly. Waveguides—

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update

which are made of a hollow pipe inserted in a hole dug deep enough to reach the shear plane—make detecting the sound a little easier. But soft materials such as clay make sounds so faint that they strain the sensing ability of even the most discriminating electronic ears.

Earlier attempts at landslide warning systems had problems that the Loughborough group has solved. Like the new device, earlier versions converted acoustical energy to digital signals. Some operated on low-frequency sound, which travels farther before it attenuates. The main drawback was that this range of frequencies is in a band that's very noisy, and the systems returned too many false positives. But high-frequency devices struggled to capture shear surface sounds because of attenuation and required off-site data processing.

The Loughborough team sidestepped these problems with a high-frequency device that takes readings at a rate of 20 to 30 kilohertz. They limited the effect of attenuation by boosting the sound with as low-tech a solution as it gets: gravel. They filled the space between the outside of the waveguide and the borehole in which it sits with gravel, which grinds as the ground around it shifts, sending noise up the waveguide.

But Dixon is quick to note that movement isn't the key indicator that a landslide is imminent—acceleration is. "If you're detecting movement of millimeters per day consistently, you need to investigate," he says. "Acceleration is cause for alarm."

LANDSLIDE LAMENT: Three days before this picture was taken, buildings stood where a landslide left a mud-lined gully through Zhouqu County, China. *PHOTO: LIAO PAN/COLOR CHINA PHOTO/AP PHOTO*

The new device measures acceleration by counting the number of times the voltage exceeds a preset threshold. Setting a floor for the signal and simply counting each time the threshold is exceeded significantly cuts the amount of data processing required and dramatically reduces extraneous noise, all without degrading the device's sensitivity. Dixon says its "hearing" is so acute that it can detect movement as tiny as 0.001 mm per minute. Though the system is continuously translating sound waves to voltages, a tally of the number of times the threshold voltage is exceeded is taken for every 15-minute period. Stable ground could deliver no hits at all, while shifting soil could generate hundreds, thousands, or hundreds of thousands of significant data points in the same time frame.

Dixon says that because geology varies and the history of a slope over many years is unique, only the acceleration of movement can offer clues to an impending landslide. Nor is there a standard time period between the sounds from the shear surface that foreshadow a massive fallout and when the landslide actually begins. A multiton chunk of earth can creep for months without breaking away, or there could be just an hour of warning.

Besides acting as an early warning system, the device can be used to measure the effectiveness of efforts to stabilize soil, such as draining or regrading, Dixon adds.

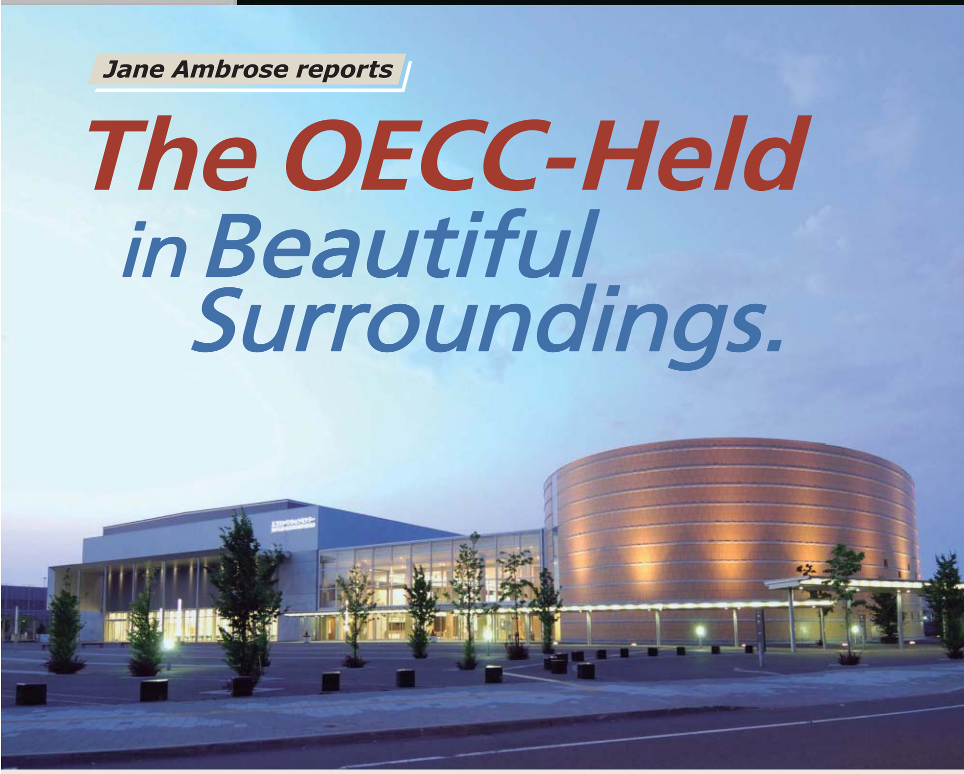
Among the tasks remaining for the group, which includes the researchers from Loughborough University and from the British Geological Survey, is refining the device's sensors and bringing down the cost, which Dixon estimates is currently a few thousand U.S. dollars. He says this is critical if the devices are going to be installed in significant numbers in poor countries where landslides claim thousands of lives each year. He says the team hopes to have a version ready for commercial production by the second quarter of 2012.

—Willie D. Jones

This article appeared online as "Sensor System Yields Landslide Warnings" in November.

Jane Ambrose reports

The OECC-Held in Beautiful Surroundings.



Sapporo Convention Center

Photo supplied by Sapporo Convention Center

The OptoElectronics and Communications Conference (OECC), was held in July this year at the Sapporo Convention Center, Hokkaido, Japan.

Why hold it in this 'snowy capital' of Japan's northernmost island? Well to say that it is experienced in hosting of international conventions of this kind would be to state the obvious. Its population of 1.9 million makes it Japan's fifth largest city – but, unlike Tokyo and Osaka which are on Japan's main island, Sapporo still retains its close connection with the pristine natural environment which surrounds it.

It is also northern Japan's leading academic center – a truly scholastic city with as many as 23 universities and colleges. Hokkaido University, recently produced a Nobel Prize winner, is perhaps the most prestigious. It is, for a start, one of the oldest national universities in Japan. Also the Chitose Institute of Science and Technology has many supportive optical communication professors.

Dr. David Moss (Associate Professor, School of Physics and Institute for Photonics and Optical Sciences in Australia), has previously lived in Tokyo and is very familiar with conventions in Japan. He says: "Sapporo Convention Center is very well laid out with lots of open spaces and coffee tables and chairs which enable us to talk and discuss between sessions – and it's an ideal environment for researchers."

Minoru Shikada, a Co-chair of OECC, says: "It was time for us to explore new sites other than Yokohama and Makuhari where our conferences have been held before. Delegates look forward to something new." Accessibility definitely had an impact on numbers and there were many more delegates from Asia this year. The opening of the Sapporo New Chitose Airport's international terminal recently certainly had a bearing on that. It makes Sapporo ideal as an international conference destination, with direct flights to and from Asian cities such as Seoul, Beijing, Shanghai, Hong Kong and Taipei. This makes access much easier for participants outside Japan.

Another Co-chair, Yuzo Yoshikuni is happy that Sapporo was chosen and says: "Sapporo attracted over 570 delegates, while the average attendance is around 400-450. The percentages of overseas delegates increased up to 50 percent whereas when the conference is held in other Japanese cities the percentage is only 20-30 percent. The number of corporate exhibitors doubled this year to 20." Costs in Sapporo are also between 10 and 30 percent less than in Tokyo.

That Sapporo is an attractive tourist destination for the Asian population both in and outwith Japan is unquestionable. That it is becoming more widely known in the world as a whole has been a gradual phenomenon. It used to be known primarily as the site of the 1972 Winter Olympics and host city for the annual Sapporo Snow Festival and people from outside the Asian continent perhaps thought of it as a winter destination.

"Aside from its wintry splendour, people are also attracted to the city by its renowned local culinary specialties, its proximity to nature and its gentle summer climate."

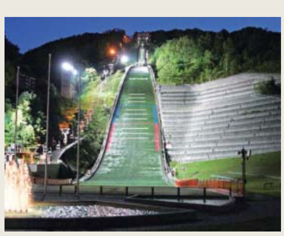
Delegates at the conference experienced a Gala Dinner in Sapporo Beer Garden, which is an old brick factory renovated into a beer hall with plenty of atmosphere. In fact, Sapporo Beer has become one of the most famous products born in the city.

Sapporo has played host to many international conferences, as it offers convenient access and an ideal conference infrastructure – in addition to its urban network and rich natural environment.

And in those aspects, Sapporo enabled the organisers of the conference to have an extremely successful event. The last word, however should go to Kimio Oguchi who was Chair of the General Affairs Committee and is a Professor at Seikei University. He has this to say: "The success of the conference depends on the host city's attractiveness."

How right he is.

Sapporo Snow Festival



Sapporo Okurayama Ski Jump

Sapporo Beer Garden

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CONTACT INFORMATION:

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MN Bidg., N1 W3, Chuo-ku, Sapporo, 060-0001, Japan
Phone: +81-11-211-3675 Fax: +81-11-232-3833
E-mail: office@conventionsapporo.jp
http://www.conventionsapporo.jp/

Japan National Tourism Organization
Japan Convention Bureau, New York Office
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E-mail: jcb@jntonyc.org
http://www.japantravelinfo.com/

Japan Tourism Agency

hands on

CAMERA HACKING

New firmware allows Canon cameras to perform some neat tricks

BACK IN THE DAY, hands-on photography required you to be closeted away in a darkened room, where you dunked sheets of paper into solutions of smelly chemicals. Now we manipulate photographs with software, a much less messy and oppressive process. But wouldn't it be great to have more control still—even before the photo is taken?

Many cameras allow you to adjust their exposure settings manually, but that's about it. What if you could have full command of your camera's hardware?

Such thoughts motivated an anonymous programmer going by the online name VitalyB to reverse engineer the firmware for Canon's PowerShot series of digital point-and-shoot cameras.

DAM NICE PHOTOGRAPHY: These aerial images of White Sands National Monument [top] and Glen Canyon Dam [middle] were taken by a Canon SD30 carried on a radio-controlled model airplane [bottom], using CHDK to operate the shutter.

With hacker-level control, he could do things the engineers at Canon had never thought of. In 2007, he made public the fruits of his labor: the Canon Hack Development Kit, or CHDK, which Andrei Gratchev, a programmer working for eASIC Corp., of Santa Clara, Calif., and other developers have since broadened. Now you can find a version for just about any one of the Canon PowerShot series.

The CHDK firmware resides on the camera's memory card, but the original Canon firmware remains on the camera's internal flash memory. So you're not likely to "brick" your camera by using CHDK inappropriately. Indeed, you can return your camera to its stock configuration merely by restarting it without CHDK on its memory card or by switching the locking tab on the card to its unlocked position. (CHDK loads only if the card is locked, and once this firmware is loaded, the camera can still record images.) The CHDK firmware is described fully on the wiki at http://www.chdk.wikia.com, which includes a "CHDK for Dummies" section and plenty of pointers for getting up and running.

Just by loading CHDK, you'll be able to coax things out of your camera that you couldn't before—saving RAW images, for example, or getting the LCD to display the battery voltage or live histograms of pixel brightness before you shoot. But the real power of CHDK comes from its ability to run scripts on your camera. You can write your own or install ones that others have posted on the CHDK wiki.

I recently tried out one of several motion-detection scripts available there. It was written by Johan Van Barel in UBASIC. (CHDK also supports the LUA scripting language.) With it, I easily converted a Canon PowerShot A630 into what a wildlife biologist or deer hunter would call a camera trap.

Most camera traps use an infrared motion detector, but a CHDK-enhanced camera can itself detect motion. Van Barel's script gives you control of such things as the delay between the motion and the shot and whether the focus is fixed or variable. Without any tuning at all of the script's parameters, I was able to get some fascinating photos of birds cavorting around the family bird feeder [see "Shutter Flutter"]. Others have used similar scripts to produce some stunning photographs of lightning.

Using another script, written by a contributor to the CHDK wiki who goes only by the name Divalent, I added what's known as an intervalometer to one of Canon's smallest cameras, the 5-megapixel SD30. I mounted the diminutive (105-gram) camera onto a radio-controlled model airplane to take aerial photos during a recent vacation to the southwestern United States. The intervalometer script allows the camera to take pictures continually at a prescribed interval—with it set at two seconds, each flight yielded a few hundred images from which I could choose a few winners. [For more CHDK-enabled imagery, see the online slideshow at http://spectrum.ieee.org/canon1210.]

I've just begun to explore the wealth of scripts available for CHDK. There are ones that have each press of the shutter button take a series of photos while varying the exposure, flash, zoom, focus, or sensitivity. You can even convert the USB port on your camera into an electronic shutter release. Of course, you're free to modify these scripts or write completely new ones. And really ambitious camera hackers can create their very own versions of CHDK, because the CHDK wiki includes the source code (written in C) and instructions for modifying it. With CHDK the sky's the limit, you might say.

—David Schneider

SHUTTER FLUTTER: A CHDK-enabled Canon camera can capture images that would be nearly impossible to take by pressing on the shutter button manually. These photos of birds in flight show what can be done with a motion-detection script.

PHOTOS, OPPOSITE AND ABOVE: DAVID SCHNEIDER

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tools & toys

CHANNEL-SURFING SURFEIT: TV buyers are overwhelmed by choice—not just by brands and size but also by complicated features like LCD backlighting, refresh rates, and pixel density.
PHOTO: JIM R. BOUNDS/BLOOMBERG/GETTY IMAGES

TV GUIDE, HD EDITION

HDTV prices keep falling, but the buying decision gets increasingly complex

THIS HOLIDAY SEASON, the rise of 3-D televisions has made it a buyer's market for plain old HD. To be sure, it's as easy as ever to get lost in a confusing tangle of technologies and acronyms. So let's simplify things. The first question involves just three letters: LED or not LED?

LED-backlit LCD screens are the premium display technology this year. They cost at least 10 percent more than the standard fluorescent-lit LCDs, but the best ones can't be beat. "The color balance is just so much better," says Randall Hand, editor of VizWorld.com.

Shoppers often begin and end their search with screen size, but pixel density and refresh rate are at least as important. Even on a low budget, it's probably worth paying for a full 1080p screen, which refreshes 1080 horizontal lines of pixels once per cycle. The 1080i sets have the same number of lines but take two clock cycles to refresh the entire screen. Here, Hand says, the price differential is so small that 1080i sets are getting rather difficult to find. "The hardware difference is minimal. Both have 1080 horizontal lines on the screen; it's just the internal guts that differ."

However, the rate at which the clock cycles is price sensitive indeed. It'll cost you "about [US] $1000 each time you double it," Hand says. TV programs with a lot of motion—sports and action movies—are noticeably smoother at 120 hertz than on a 60-Hz set, Hand says.

But going even higher—rates of 240 Hz or even 480 Hz—may not be worth the extra premium, unless you're also getting into 3-D—which is another story altogether [see the August online special report "3-D in the Home"].

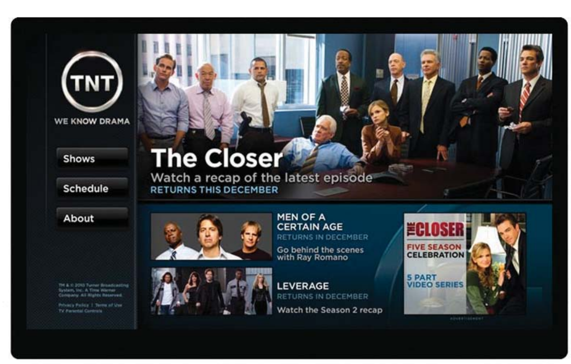
When Scott Steinberg of Seattle-based tech consulting firm TechSavvy Global bought his HDTV, he decided against a 50-inch model with so-so specs and instead bought a comparably priced 42-inch TV that had a higher refresh rate and better picture quality.

"The reality is, once you get used to the set, you're not going to say, 'God, I miss those 8 inches,' " he says. "If the picture quality across the board is better, who cares if it's 42 or 50 inches?"

To be sure, screen size does count for something. Less than about 32 inches—the exact number depends on the manufacturer—probably means the screen wasn't even made by the manufacturer whose brand name graces the front of the set.

"Once you go above a certain size, the company actually builds the screens themselves," Hand says. Below that, "they're just buying them from some no-name Chinese or Taiwanese redistributor."

Once upon a time you could avoid getting stuck with the subpar output



NET GAIN: Many new sets offer Internet connectivity to a confusing abundance of new services such as Netflix, Hulu, iTunes, and Google TV, shown here.
IMAGE: GOOGLE

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of an anonymous subcontractor by finding the manufacturer's signature model—Sharp's Aquos line of HDTVs, for instance, or Sony's Bravia—and noting what the smallest screen size was for that model line. It was a good bet that any screen below that size would be knockoff priced and knockoff quality. Today, though, Bravias come as small as 22 inches—a size that Sony itself is unlikely to manufacture.

Although there's no substitute for seeing the television on the showroom floor, Steinberg says, extra points go to the savvy shopper who goes home afterward, researches the alternatives, and buys the chosen set on the retailer's Web site. (When searching the Web by the name of the desired set and retailer, it pays to include the phrase "coupon code"; you might be able to knock another 10 to 20 percent off the retail price.)

Finally, consider the merits of putting the Internet on the TV itself. Samsung, LG, Sony, and Vizio are among the manufacturers adding net connectivity to their top-tier HDTV models—complete with apps that provide access to social networking sites, Netflix and other streaming video, and online music services like Pandora and Last.fm. But, Steinberg adds, remember that the best deal might still be to buy a "dumb" set and connect to the Internet via another box.

"If you purchase a PlayStation 3 for $300, for example," he says, "You're getting a Blu-ray player that also has a massive library of content with the ability to stream music, movies and photos, and download games."

—Mark Anderson

SQUINT-FREE: When appliances go digital, some difficult tasks become easy. The Brother Quattro 6000D sewing machine shown here has a camera above the needle plate that shows the stitching area on a built-in LCD screen.
PHOTO: BROTHER INTERNATIONAL

A DIFFERENT KIND OF MULTITHREADING

Today's sewing machines are sophisticated embedded systems with exacting precision, automated stitch control, and touch-screen interfaces

My Aunt Yetta sewed quilts—and most of her family's clothes—on an antique treadle sewing machine that was powered by her foot.

The next 50 years of technological innovation added electricity and the zigzag stitch—and that was fine. As long as a machine could stitch patches of fabric to one another to create a quilt top (called piecing) and could sew together the quilt's bottom and top layers with batting in between (the actual quilting), we quilters could make our pretty blankets, quietly upgrading from one machine to another without missing a stitch.

Today, though, if you open up a high-end sewing machine, you'll find that inside it's eerily akin to your latest PC—jammed full of printed circuit boards, USB ports, memory cards, and user interfaces driven by touch screens.

Even a modest sewing machine has hundreds of built-in stitches, and the expensive models—wow. Bernina's stitch regulator, a gizmo that attaches to higher-end machines, ensures that free-motion quilting stitches are even; the device reads the movement of the fabric as you push it past the needle and adjusts the motor speed accordingly. One Brother model's LCD offers a "needle's-eye view" that lets a quilter line up the work exactly; precision is an important consideration for many quilting techniques. (One look at my own wandering quilting rows shows why.) Other features recognize the distance between the seam line and the edge of the fabric, even on gentle curves. Quilters care about quarter-inch seams because even slight inaccuracies in quilt blocks, of which there may be hundreds, compound themselves across a quilt that's three meters wide.

tools & toys

An average quilter will be delighted that the sewing machine threads the needle by itself and will never peer inside the box to find the servomotors and light-tripped switches. Almost everything is done in software anyway; in many machines, the only mechanical parts are those servomotors, video controllers, USB connectors, and the needle assembly and bobbin. "For us, it's really printing with thread," explains Dean Shulman, the senior vice president of Brother's sewing division.

The embedded software on a sewing machine's system board is almost all custom written—this is one domain not dominated by Windows Embedded CE. You download updates from the manufacturer's Web site onto a USB key that plugs into the sewing machine. You can also use the USB port to save and copy embroidery designs.

All these features are designed to help amateur quilters get professional results. The high-end sewing machines—which start at about US $6000 and can cost more than $10 000—help quilters work with more speed and accuracy, and best of all, avoid much of the tedium of an essentially repetitive craft.

The tech revolution goes beyond the sewing machines themselves. We can now scan images, create flashy kaleidoscope effects in Adobe Photoshop, and print the results directly onto fabric. Even a duffer like me can add nice touches, such as the engagement photo I put on the label of my niece's wedding quilt.

To be sure, hardware and software bring frustrations as well as opportunities. "Computerized technologies can be fickle and fragile," complains Stephanie Gordon, the owner of Swamp Quilts, in Gainesville, Fla. "I can understand the allure of a very high-tech computer, but I like to stick with the basics. My machine is not digital, but it is high quality, durable, and does exactly what I need it to do."

Still, most quilters have happily moved into the 21st century. "The sewing machine has opened up the gates of faster creative expression," says Bonnie Lyn McCaffery, a quilting book author and instructor who's been quilting for 27 years. McCaffery has learned to create continuous line designs for beautiful bobbin embroidery, using techniques that can't be duplicated by hand.

As in chess, automotive manufacturing, Lasik surgery, and a thousand other activities, human-machine collaboration can be a beautiful and productive thing.

—Esther Schindler

QUILTING 2.0

Whether it's mothers and daughters or large quilting bees, quilting has always been a social activity, one in which women (and occasionally men) come together to sew and quilt, sharing experiences and techniques. Thus it's no surprise that quilting has become a "Web 2.0" activity. Online communities are active and vibrant—and have long ago moved beyond e-mail lists, discussion forums, and their modern equivalents, Facebook and Twitter.

Galleries

Sites like The Quilt Show, Fons & Porter's Love of Quilting, and Quiltcetera.com offer video instruction, shared quilt galleries, and discussion forums.

http://www.thequiltshow.com
http://www.fonsandporter.com
http://www.quiltcetera.com

Software

Applications like Electric Quilt and Quilt-Pro are customized CAD applications that help quilters design quilt blocks, estimate fabric yardage, visualize patterns, and audition colors. Their online forums encourage quilters to share their completed designs; even a mystery book author (of quilting-related novels) has gotten into the spirit.

http://www.electricquilt.com
http://www.electricquilt.com/Users/FunStuff/BenniHarper/BenniHarper.asp
http://www.quiltpro.com

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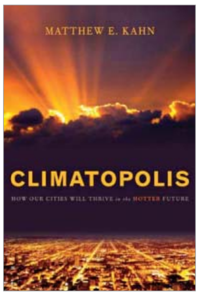
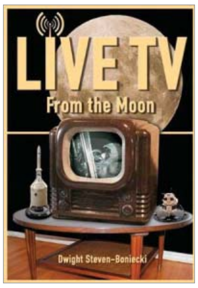
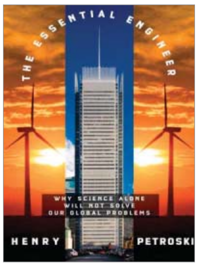


Climatopolis: How Our Cities Will Thrive in the Hotter Future
By Matthew E. Kahn; Basic Books, 2010; 274 pp.; US $26.95; ISBN: 978-0-4650-1926-7
Reviewed by Dave Levitan



Live TV From the Moon
By Dwight Steven-Boniecki; Apogee Books, 2010; 248 pp. (plus DVD); US $25.95; ISBN: 978-1-926592-16-9
Reviewed by Kieron Murphy



The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems
By Henry Petroski; Alfred A. Knopf, 2010; 288 pp.; US $26.95; ISBN: 978-0-307-27245-4
Reviewed by Kenneth R. Foster

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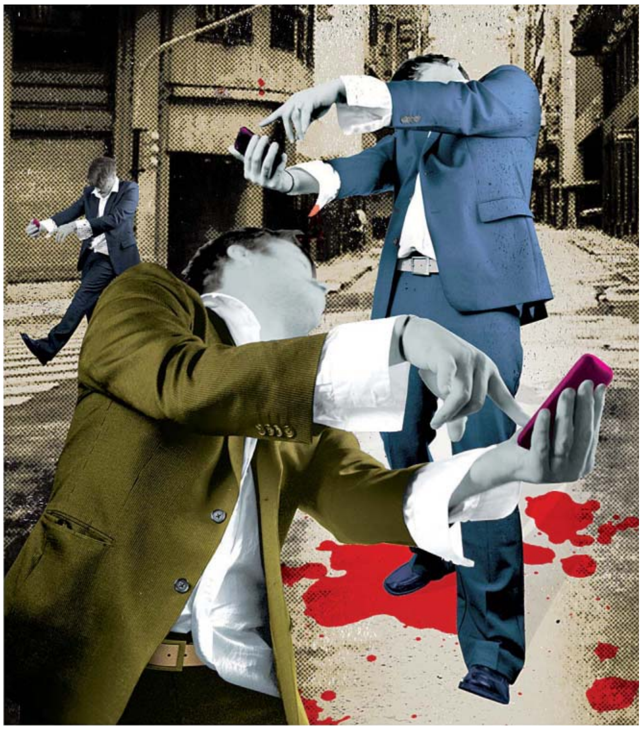
technically speaking

BY PAUL McFEDRIES



GLUEKIT

Day of the Living Dead

We can't stop the march of technology, but we need to halt the iPod pedestrian, cycle, and driver zombies.
—**Edmund King, president, The Automobile Association (UK)**

I FIRST REALIZED a zombie apocalypse was upon us when I read about Email 'n Walk, an iPhone app that turns on the phone's camera while you compose e-mail. To take a picture to use as an attachment, right? Oh no, that would be *so* 2009. The idea, as the app's name implies, is to let you read or compose messages and walk at the same time, all the while remaining "safe" because the camera lets you see what's happening on the other side of your phone.

That someone would even conceive of such an app means that we now live in a world where people regularly—you might even say compulsively—read and compose e-mail while walking down the street. But that's not all people do while power walking to their next appointments. They also text, read Facebook and Twitter status updates, scan RSS feeds, and more than anything else, they bliss out to their favorite tunes at unhealthily loud volume levels.

Of course, while they're immersed in their digital worlds, these **iPod pedestrians** (or, inevitably, **iPodestrians**) are also careening through the real world, heedless of their fellow citizens and oblivious to the city's dangers. They have become, in fact, **iPod zombies**, a digital undead army lurching through the streets. We may call it the **iPod zombie trance**, but it's a device-agnostic state, since this living dead horde also consists of **iPhone zombies**, **BlackBerry zombies**, and the generic **MP3 zombies** and **cellphone zombies**.

The **iPod zombie pedestrian** isn't alone in needing earbuds and a tiny screen these days. Others in a state of **iPod oblivion** include **iPod zombie joggers**, **iPod zombie dog walkers**, **iPod zombie cyclists**, and **iPod zombie rollerbladers**. Similarly, in your local Starbucks, you've probably seen your share of **laptop zombies** who are oblivious to everyone and everything except the screen in front of them.

If **walking while texting** and other forms of **pedestrian inattention** were merely comical, no one would worry about them too much. But attention is a zero-sum game, so concentrating on your iPod results in a **technological autism** or **unintentional blindness** that can lead to near collisions with fellow pedestrians and actual collisions with street lamps. One study found digital music players to blame for up to 17 accidents every day in the United Kingdom.

The preferred term for this among cognitive scientists is *inattentional blindness*, which they define as "the failure to detect the appearance of an unexpected, task-irrelevant object in the visual field." So if you're zoned out listening to Arcade Fire at top volume (the task) and you fail to see an oncoming vehicle (the unexpected, task-irrelevant object), that's **IB**, and that's probably trouble, perhaps even **death by iPod**.

The risks increase if the driver of the car bearing down on you is preoccupied reading or sending text messages, a form of digital drunkenness known as being **intexticated**. An incredibly dangerous habit, **intextication** is also called **DWT**, or **driving while texting**. If the driver is preoccupied with a cellphone call instead, call it **DWY**, or **driving while yakking**—abbreviations that play on the legal term DWI, or driving while intoxicated.

What's the solution? It's almost certainly not government regulation, such as the law proposed a couple of years ago by New York State Senator Carl Kruger that would have made it illegal to use a crosswalk while listening to an MP3 player or conducting a cellphone conversation. New York City famously doesn't even enforce its jaywalking laws. Then there's the idea tried in East London's Brick Lane, where the street's many bollards were covered with padded cushions to allow, one assumes, for easier ricocheting. Alas, the pads were a mere publicity stunt, and Brick Lane remains as dangerous as ever. Perhaps the best idea is simply to watch out for each other. The next time you see an iPod zombie heading straight for a lamppost or about to walk into the path of an onrushing vehicle, a quick "Heads up!" might save the day. For best results, text it. ❑

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His stunning prophecies have earned him a reputation as **a tech visionary,** but many of them don't look so good on close inspection

Ray Kurzweil's Slippery Futurism

BY JOHN RENNIE ILLUSTRATIONS BY MATT MAHURIN

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DON'T PANIC IF YOU LOOK for your computer today and can't find it. We have it on the authority of technology maven Ray Kurzweil that this year computers will have vanished because of miniaturization. As he said at the TED conference in February 2005:

> *By 2010 computers will disappear. They'll be so small, they'll be embedded in our clothing, in our environment. Images will be written directly to our retina, providing full-immersion virtual reality, augmented real reality. We'll be interacting with virtual personalities.*

If you have a different impression of the world today, Kurzweil would want you to know that he is technically correct. If the rest of the world fails to think that's enough, the rest of the world is wrong.

Of course, Kurzweil did not mean to say that all computers would actually disappear. Rather, embedded microprocessors would allow many of the functions once uniquely served by computers to disseminate to phones, tablet computers, and even cars, clothes, and key chains. And in that sense, 2010 might indeed be seen as a ringing vindication of Kurzweil's prophecy, because smartphones and iPads are everywhere.

But a moment's reflection reveals that expansive interpretation of Kurzweil's remarks to be, at bottom, insipid. Here's why: Many of those same devices were already popular commercial products in 2005. Stylus-based computer interfaces have been around since at least the 1980s. Microsoft introduced pocket and tablet versions of Windows in 2000 and 2001. Smartphones and PDAs emerged in the mid-1990s. Handspring brought out the Palm OS Treo in 2002. The RIM BlackBerry smartphone also came out in 2002.

So by Kurzweil's soft definition, the computer had already disappeared when he was on stage in 2005. In fact, much of his audience may have had its replacements in their pockets. If his rhetoric about computers disappearing by 2010 isn't meant to be taken literally, then essentially all that's left is the claim that smartphones and other digital devices would get smarter, smaller, and more popular, which would not win any prizes for sagacity.

Therein lie the frustrations of Kurzweil's brand of tech punditry. On close examination, his clearest and most successful predictions often lack originality or profundity. And most of his predictions come with so many loopholes that they border on the unfalsifiable. Yet he continues to be taken seriously enough as an oracle of technology to command very impressive speaker fees at pricey conferences, to author best-selling books, and to have cofounded Singularity University, where executives and others are paying quite handsomely to learn how to plan for the not-too-distant day when those disappearing computers will make humans both obsolete and immortal.

Scorecard

Ray Kurzweil's assessment of his own 108 predictions from his 1999 book, *The Age of Spiritual Machines*

89 "Entirely correct" (by end of 2009)

13 "Essentially correct" (realized within just a few years)

3 "Partially correct"

2 "10 years off"

1 "Just wrong"

RAY KURZWEIL'S GENIUS is beyond dispute. He has been awarded the National Medal of Technology, a Lemelson-MIT Prize, and a raft of other international accolades and honorary degrees. He is in the National Inventors Hall of Fame in the United States. In high school he wrote software that could compose music in the style of classical composers (an achievement that earned him an appearance on the TV game show "I've Got a Secret" in 1965). He invented the first optical scanner capable of interpreting writing in any typeface, then directed the further development of the first CCD flatbed scanner and text-to-speech synthesizer so that he could build the Kurzweil Reading Machine for the blind. He has developed commercial speech recognition systems used around the world, founded a number of companies and started a hedge fund.

And yet, while garnering honors for his brilliance, Kurzweil has also become famous (or notorious) for his views on the technological future, which he has outlined in the best-selling books *The Age of Intelligent Machines* (1990), *The Age of Spiritual Machines* (1999), and *The Singularity Is Near* (2005). In brief, they describe his discovery of a "law of accelerating returns" that governs technological progress. Computer intelligence and other technologies will evolve exponentially fast, he says, bringing true artificial intelligence, human immortality, and fantastic nanoengineering capabilities within a very few decades. Within the century, they will push history to a technological singularity literally beyond imagination.

Kurzweil is confident, for instance, that by 2029 researchers, having reverse engineered the human brain, will build an AI that can pass as human. (He has a US $20 000 bet to that effect with computing pioneer Mitchell Kapor riding at the Long Bets Web site.) Neuroscientists, AI researchers, and others have objected that no one today has more than the faintest idea of how to accomplish these feats and that his time line is highly unrealistic. Kurzweil dismisses all such objections: The obstacles will undoubtedly melt away in the face of Moore's Law and the unstoppable acceleration of technology.

In his talks, Kurzweil says he began studying rates of technological change because he realized that a major reason tech businesses fail is not that they fail to build what they intend but that their timing is wrong: By the time their innovations come to market, the opportunity is past, having become irrelevant or having been seized by someone and something else. To help spread the gospel of accelerating returns, Kurzweil and entrepreneur Peter Diamandis established the Singularity University, in California, which offers 9-day executive training sessions (for $15 000) and 10-week graduate studies (for $25 000) on how to understand and master exponentially advancing technologies.

All these enterprises ride on the credibility of Kurzweil's vision. Since he began publishing his predictions 20 years ago, it is worth assessing their accuracy to date. Unfortunately, scoring Kurzweil's prophecies turns out to be a difficult and contentious exercise.

PAEANS TO KURZWEIL'S oracular prowess often begin by noting that in his 1990 book, *The Age of Intelligent Machines*, Kurzweil predicted the rise of the Internet as a medium for public communications, commerce, education, and entertainment. "By early in the next century, personal computers will be portable laptop devices containing cellular phone technology or wireless communications with both people and machines. Our portable computers will be gateways to international networks of libraries, data bases, and information services..." he wrote.

The World Bank estimates that in 1990 only about 2 million people had Internet access. By 2000 that number had grown to 124 million with the transformative and all-consuming rise of the World Wide Web. On those grounds, Kurzweil's prediction might seem to be a gem. Nevertheless, some facts scuff its luster.

The first is that to see, in 1990, a society using networked computers for everyday tasks, you didn't need to be prophetic. You just needed to be French. France's government began issuing dumb terminals to telephone subscribers for free in 1981 to encourage use of the paid Minitel online information, or videotex, service. Minitel allowed users to look up phone numbers, purchase train and airline tickets, use message boards and databases, and purchase items through mail order.

"The French use almost three million computer terminals to perform such tasks as looking up phone numbers electronically and communicating with strangers over what has been dubbed the 'electronic singles bar,'" notes a 15 September 1987 article by Andrew Pollock in *The New York Times*.

That same article began by lamenting that, in the United States, "The vision of an electronic society in which consumers read the news, pay bills and make airplane reservations on their home computers has proved illusory." In other words, three years before Kurzweil's book, some people had not only imagined an online society but had already questioned whether it could catch on in the United States. Even so, by the late 1980s, CompuServe, GEnie, Prodigy, Dow Jones News/Retrieval, and other commercial services were offering e-mail, conversation, information, and entertainment to subscribers with personal computers who were willing to pay up to $12 per minute for the privilege. The Videotex Industry Association estimated that in 1987, 40 such online services were serving 750 000 consumers. In addition, hundreds, perhaps thousands, of noncommercial electronic bulletin boards also served various interests over the phone lines.

What kept these services from mainstream success was high costs and technical difficulties. Pollock's article quotes Gary Arlen, publisher of the industry newsletter *Interactivity Report*, as saying that videotex "is languishing, and everyone is sort of waiting for the next breakthrough."

That breakthrough would of course be the invention of the World Wide Web, which Tim Berners-Lee proposed in 1989 and which debuted publicly in December 1993. The Web made the Internet easier, cheaper, and more adaptable for more users. But the early-adopting portion of the public had demonstrated an appetite for online services years earlier.

Popular culture in the late 1980s was also not short on visions of a heavily computerized, network-linked society. Most of these owed a debt to William Gibson's hit 1984 novel *Neuromancer*, a seminal work of "cyberpunk" fiction that popularized the term *cyberspace*. Rather famously, Gibson has said he didn't know anything about computers when he wrote *Neuromancer*, so his vision didn't come from any remarkable insight into the technology. He was simply picking up on ideas that were already abroad in films such as *Bladerunner* and *Tron* from 1982, and in such novels as Bruce Sterling's 1988 award-winner *Islands in the Net* and the 1989 Japanese manga series *Ghost in the Shell*.

The fact that many sources anticipated Kurzweil's prediction of a vigorous online society does not discredit it. But the praise that congratulates him for the originality of the idea implicitly obscures all those others who did it before him.

KURZWEIL MAKES LOTS OF PREDICTIONS. He really hit his stride in *The Age of Spiritual Machines*, in 1999, which included specific claims about what life would be like in 2009. (And that's just for openers: The book offers scenarios by decades up through 2099 and then speculates about how intelligences will contemplate the universe millennia from now.)

Kurzweil got a lot right. But in instance after instance, his unambiguously correct statements are wedded to others that sound close to reality...but are also somewhat off. They're like descriptions of the world as seen through a fish-eye lens.

"It is now 2009. Individuals primarily use portable computers, which have become dramatically lighter and thinner than the notebook computers of ten years earlier. Personal computers are available in a wide range of sizes and shapes," he wrote, and if he had ended the sentence there, surely no one would disagree. But instead he continues: "—and are commonly embedded in clothing and jewelry such as wristwatches, rings, earrings, and other body ornaments. Computers with a high-resolution visual interface range from rings and pins and credit cards up to the size of a thin book." And: "People typically have at least a dozen computers on and around their bodies, which are networked using 'body LANs' (local area networks)."

Is that all true? Accept for now that smartphones, music players, and even chip-enabled credit cards should all count as computers because they contain a microprocessor, and that they can even be loosely called

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jewelry, clothing, or body ornaments. Even so, how many of us have more than a dozen of these "computers" on our persons? Beyond a Bluetooth-coupled phone and earpiece, how many are in any sense networked together? How many sport a "high-resolution visual interface"?

Or consider what Kurzweil wrote about education. He correctly projects that technology will play a much larger role in the classroom and that distance learning and teaching software will trend upward. But he also asserted that students would own and use computers that weigh less than a pound, with which they would interact primarily by voice and stylus. Teachers would "attend primarily to issues of motivation, psychological well-being, and socialization," while software handles instruction. Is this a recognizable, accurate description of schools today?

> "So far, I haven't seen Kurzweil straight-up admit that he was wrong. I think he would benefit from doing so on some of these points"
>
> ***Michael Anissimov,*** Accelerating Future blog

He also seems to have had high hopes a decade ago for the antitumor compounds called angiogenesis inhibitors. His footnotes direct attention to a front-page *New York Times* story from 3 May 1998 that is notorious in science-writing circles for having grossly overhyped the promise of the research. In his book's formal discussion, Kurzweil merely suggests that angiogenesis inhibitors would help to reduce cancer. Yet in a puckish chapter where Kurzweil chats with a fictional interviewer from the future, he has her say that his prediction was "actually quite understated. Bio-engineered treatments, particularly antiangiogenesis drugs...have eliminated most forms of cancer as a major killer." To which Kurzweil replies, "Well, that's just not a prediction I was willing to make." Talk about having it both ways.

IT SEEMS ONLY FAIR to allow some latitude for interpretation on the dates. But even then, it is hard to define the rightness or wrongness of Kurzweil's predictions.

Kurzweil himself has no such difficulty, however. He knows precisely how well he's doing. Last January, Michael Anissimov of the Accelerating Future Web site posted an item in which he suggested that seven of Kurzweil's predictions for 2009 seemed to be wrong. Kurzweil replied with a note that argued it was wrong to single out merely seven predictions when he had actually made 108 in *The Age of Spiritual Machines*.

"I am in the process of writing a prediction-by-prediction analysis of these, which will be available soon and I will send it to you," he wrote. "But to summarize, of these 108 predictions, 89 were entirely correct by the end of 2009." Another 13 were "essentially correct," by which he meant that they would be realized within just a few years. "Another 3 are partially correct, 2 look like they are about 10 years off, and 1, which was tongue in cheek anyway, was just wrong," he wrote. So by his own scoring, he is at least 94.4 percent accurate.

Kurzweil has not yet released that analysis of his track record, so it is hard to know how some of his predictions for 2009—the adoption of intelligent highways and self-piloting cars, sharp reductions in cancer, and continuous economic growth for the United States and the stock market through 2019, for example—fit into his tally. Maybe one of those was meant tongue in cheek, or maybe he doesn't regard them as real predictions; otherwise, it seems as though he regards all of them as at least partly or imminently correct. Judge for yourself.

Based on Kurzweil's defenses of the items that Anissimov had questioned, however, his analysis seems unlikely to satisfy his critics. For instance, Kurzweil stood by his assertion that in 2009, 3-D chip architectures would be common. "Many if not most semiconductors fabricated today are in fact 3D chips, using vertical stacking technology," he wrote. "It is obviously only the beginning of a broad trend, but it is the case that three-dimensional chips are commonly used today."

Actually, 3-D integrated circuits are currently very much a niche product, with limited uses in DRAM, image sensors, and a few other applications. A market survey by Yole Développement, in Lyon, France, from 2008 projected that by 2015 3-D devices would represent about 25 percent of the memory market and only about 6 percent of the rest of the semiconductor market. Kurzweil is surely right that 3-D chips will become widespread within another few years, but it is simply wrong to insist that they already are.

Kurzweil also stands by his claim that computer displays built into eyeglasses would project images into users' eyes because some such systems do exist, and says, "The prediction did not say that all displays would be this way or that it would be the majority, or even common." Similarly, he defends his claim that translation software would be "commonly used" to allow people speaking different languages to communicate by phone by pointing to smartphone apps that emerged at the end of 2009. He allows that one could quibble about how "common" their use is.

"So far, I haven't seen Kurzweil straight-up admit that he was wrong. I think he would benefit from doing so on some of these points," says the blog post by Anissimov, who seems to admire the man but thinks futurists should be accountable for their statements.

Kurzweil's reply asserts that he is all for futurist accountability, "but such reviews need to be free of bias, fair, and not subject to selection bias and myopic interpretations of both the words used and the current reality." Still, it is hard to square his objection to "myopic," literal interpretations with his lawyerly defenses of his predictions that hinge on their precise wording and creative interpretations of the meaning of everyday words.

KURZWEIL IS EXTREMELY WELL INFORMED about technologies in development and highly insightful about how they can feed into one another, particularly over the relatively near term. He is very good on trends, and his predictions are thought provoking. For the people who pay to hear him speak or to read his books, perhaps that is enough.

On the other hand, if Kurzweil is right that a failure to understand the timing of technological change is a major reason that businesses fail, then let's hope that nobody listening to Kurzweil takes his predictions at strict face value. Anyone who was encouraged to hit the market during the '90s with products or services contingent on cybernetic chauffeurs or widespread, foolproof, real-time speech translation could be in trouble.

COMMENT at http://spectrum.ieee.org/kurzweil1210

Nevertheless, his unwavering confidence in the law of accelerating returns allows him to shrug off contradictory facts and perspectives as mere temporary inconveniences. A year here, a decade there: The accelerating returns of technology will sweep them all away en route to a singularity beyond human imagination ruled by one eternal truth—that Ray Kurzweil was, is, and always will be right.

At least 94.4 percent of the time, anyway. ❑

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Transportation of goods and people plays a vital role in the lives of everyone and in virtually all businesses on earth. The cost of transportation, both personal and freight, accounts for a significant share in the global economy. Traditionally, transportation has been divided into three categories: land (automobiles, trucks, and rail); air; and water. There are four societies in IEEE Division IX addressing these issues, namely the Aerospace and Electronics Systems Society (AESS), the Intelligent Transportation Systems Society (ITSS), the Oceanic Engineering Society (OES), and the Vehicular Technology Society (VTS). Each of these societies addresses issues in a particular mode of transportation. However, there are many issues affecting all of these modes of transportation in the face of increasing demand. Some of the issues include congestion, environmental impact, and energy sources.

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Meet MoNETA—the brain-inspired chip that will outsmart us all

The Brain of a New Machine

BY MASSIMILIANO VERSACE & BEN CHANDLER
ILLUSTRATIONS BY CHAD HAGEN

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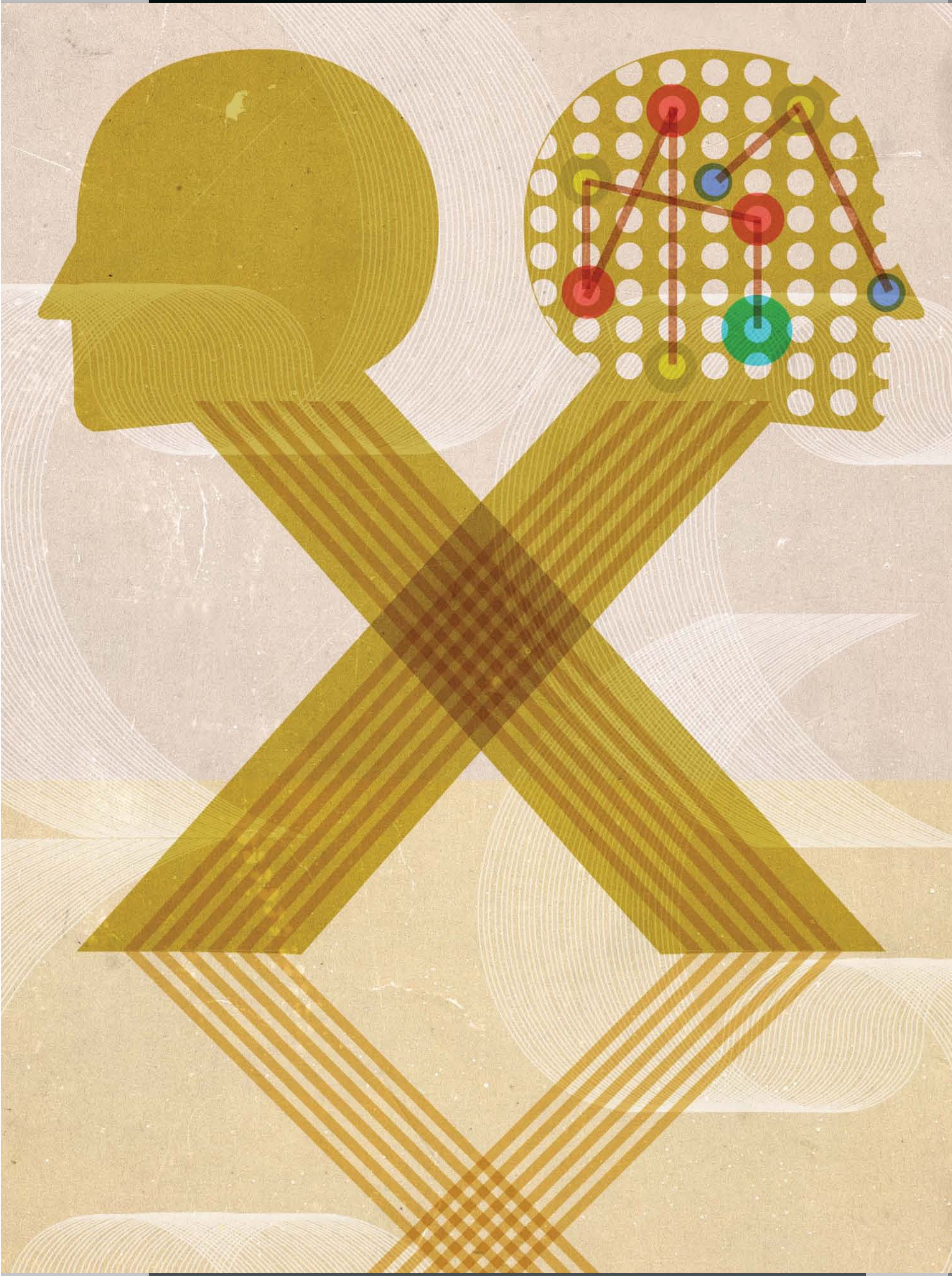


STOP US IF YOU'VE HEARD THIS ONE BEFORE: In the near future, we'll be able to build machines that learn, reason, and even emote their way to solving problems, the way people do.

If you've ever been interested in artificial intelligence, you've seen that promise broken countless times. Way back in the 1960s, the relatively recent invention of the transistor prompted breathless predictions that machines would outsmart their human handlers within 20 years. Now, 50 years later, it seems the best we can do is automated tech support, intoned with a preternatural calm that may or may not send callers into a murderous rage.

So why should you believe us when we say we finally have the technology that will lead to a true artificial intelligence? Because of MoNETA, the brain on a chip. MoNETA (Modular Neural Exploring Traveling Agent) is the software we're designing at Boston University's department of cognitive and neural systems, which will run on a brain-inspired microprocessor under development at HP Labs in California. It will function according to the principles that distinguish us mammals most profoundly from our fast but witless machines. MoNETA (the goddess of memory—cute, huh?) will do things no computer ever has. It will perceive its surroundings, decide which information is useful, integrate that information into the emerging structure of its reality, and in some applications, formulate plans that will ensure its survival. In other words, MoNETA will be motivated by the same drives that motivate cockroaches, cats, and humans.

Researchers have suspected for decades that real artificial intelligence can't be done on traditional hardware, with its rigid adherence to Boolean logic and vast separation between memory and processing. But that knowledge was of little use until about two years ago, when HP built a new class of electronic device called a memristor. Before the memristor, it would have been impossible to create something with the form factor of a brain, the low power requirements, and the instantaneous internal communications. Turns out that those three things are key to making anything that resembles the brain and thus can be trained and coaxed to behave like a brain. In this case, form is function, or more accurately, function is hopeless without form.

Basically, memristors are small enough, cheap enough, and efficient enough to fill the bill. Perhaps most important, they have key characteristics that resemble those of synapses. That's why they will be a crucial enabler of an artificial intelligence worthy of the term.

The entity bankrolling the research that will yield this new artificial intelligence is the U.S. Defense Advanced Research Projects Agency (DARPA). When work on the brain-inspired microprocessor is complete, MoNETA's first starring role will likely be in the U.S. military, standing in for irreplaceable humans in scout vehicles searching for roadside bombs or navigating hostile terrain. But we don't expect it to spend much time confined to a niche. Within five years, powerful, brainlike systems will run on cheap and widely available hardware.

How brainlike? We're not sure. But we expect that the changes MoNETA will foment in the electronics industry over the next couple of decades will be astounding.

ARTIFICIAL INTELLIGENCE hasn't stood still over the past half century, even if we never got the humanlike assistants that some thought we'd have by now. Computers diagnose patients over the Internet. High-end cars help keep you from straying out of your lane. Gmail's Priority Inbox does a pretty decent job of prioritizing your e-mails.

But even the most helpful AI must be programmed explicitly to carry out its one specific task. What we want is a general-purpose intelligence that can be set loose on any problem; one that can adapt to a new environment without having to be retrained constantly; one that can tease the single significant morsel out of a gluttonous banquet of information the way we humans have evolved to do over millions of years.

Think about that MoNETA-enabled military scout vehicle for a moment. It will be able to go into a mission with partially known objectives that change suddenly. It will be able to negotiate unfamiliar terrain, recognize a pattern that indicates hostile activity, make a new plan, and hightail it out of the hostile area. If the road is blocked, it will be able to make a spur-of-the-moment decision and go off-road to get home. Intuition, pattern recognition, improvisation, and the ability to negotiate ambiguity: All of these things are done really well by mammalian brains—and absolutely abysmally by today's microprocessors and software.

Consider Deep Blue, IBM's 1.4-ton supercomputer, which in 1997 faced then world chess champion Garry Kasparov. In prior years, Kasparov had defeated the computer's predecessors five times. After a taut series comprising one win apiece and three draws, Deep Blue finally trounced Kasparov in game six. Nevertheless, Deep Blue was not intelligent. To beat Kasparov, its special-purpose hardware used a brute-force strategy of simply calculating the value of 200 million possible chess moves each second. In the same amount of time, Kasparov could plan roughly two chess positions.

Over the next 10 years, computing capabilities skyrocketed: By 2007 the processing power of that 1.4-ton supercomputer had been contained within a Cell microprocessor roughly the size of a thumbnail. In the decade between them, transistor counts had jumped from 7.5 million on an Intel Pentium II to 234 million on the Cell. But that explosion of computing power did not bring artificial intelligence the slightest bit closer, as DARPA's Grand Challenge has amply demonstrated.

DARPA had launched the Grand Challenge to create autonomous vehicles that could drive themselves without human intervention. AI had been credited (again) with a major victory, when Stanley, Stanford's Volkswagen Touareg, drove itself 212 kilometers (132 miles) across California's Mojave desert to claim the US $2 million prize. One giant leap for AI!

Not really. The next phase of DARPA's challenge upped the ante, demanding AI-controlled cars whose intelligence could conquer not just the wide-open desert but busy city streets. For eight days in 2007, DARPA set research teams loose on George Air Force Base, a desolate speck in Victorville, Calif. This time, the cars had to navigate basic traffic conditions according to California law, merging, passing, parking, negotiating intersections—the stuff most American teenagers can do by age 16.

The results were sobering. Cars tricked out with state-of-the-art sensors, positioning systems, and in one case, 14 blade servers, were utterly undone by obstacles as common as a breadbox-size rock. Within a few hours, almost half the teams had been removed from the race for such infractions as running amok in a parking lot or smashing into each other while trying to share a single lane on a road.

Now consider the humble rat. Its biological intelligence uses general-purpose "wetware"—the biochemical hardware and software puree that is the brain—to solve tasks like those of the Grand Challenge cars, with much better results. First, a hungry rat will explore creatively for food. It might follow familiar, memorized routes that it has learned are safe, but at the same time it must integrate signals from different senses as it encounters various objects in the environment. The rat can recognize dangerous objects such as a mousetrap and will often avoid them even though it may never have seen the object at that particular angle before. After eating, the rat can quickly disengage its current plan and switch to its next priority. All these simultaneous challenges, with all their varied complexities, are impractical for a machine, because you can't fit a computer that size into a vehicle smaller than a semi. And yet they are negotiated by a brain whose networks of millions of neurons and billions of synapses are distributed across many brain areas—a brain that weighs no more than 2 grams and can operate on the power budget of a Christmas-tree bulb.

Why is the rat brain so superior? In a word, architecture. The brain of an adult rat is composed of 21 million nerve cells called neurons (the human brain has about 100 billion). Neurons talk to each other by way of dendrites and axons. You can think of these tendrils as the in-boxes (dendrites) and out-boxes (axons) of the individual neuron, transmitting electrical impulses from one neuron to another. Most of the processing performed in the nervous system happens in the junctions between neurons. Such a junction, between one neuron's dendrite and a neighboring neuron's axon, is a space called a synapse.

Computational neuroscience has focused largely on building software that can simulate or replicate a mammal's brain in the classic von Neumann computer architecture. This architecture separates the place where data is processed from the place where it is stored, and it has been the staple of computer architectures since the 1960s [see sidebar, "The Great Brain Race"]. Researchers figured that, given enough powerful CPUs, creating programs that emulate the "software" of the brain is a logical outcome.

But that's a little like saying that given enough words, creating a novel is the logical outcome. Architecture is key here. To understand why, compare the path of a hypothetical bit of data inside a conventional microprocessor with its path inside a brain.

Recall that on a standard computer, the memory and processor are separated by a data channel, or bus, between the area where the data's stored and where it's worked on [see illustration, "Hardware vs. Wetware"]. That channel's fixed capacity means that only limited amounts of data can be "checked out" and worked on at any given instant. The processor reserves a small number of slots, called registers, for storing data during computation. After doing all the necessary computation, the processor writes the result back to memory—again, using the data bus. Usually, this routine doesn't pose much of a problem: To minimize the amount of traffic flowing on the fixed-capacity bus, most modern processors augment the registers with a cache memory that provides temporary storage very close to the point of computation. If an often-repeated computation demands multiple pieces of data, the processor will keep them in that cache, which the computational unit can then access much more quickly and more efficiently than it can the main memory.

However, that caching scheme won't work for the sort of computational challenges you'd encounter trying to simulate a brain. Even relatively simple brains have tens of millions of neurons connected by billions of synapses, so any attempt to simulate such a vast interconnection would gobble up a cache as big as the computer's main memory—which would render the machine immediately useless.

Why? The vast majority of the computing and power budget of such a brain-simulating system—computer scientists call it a neuromorphic architecture—goes to mimicking the sort of signal processing that happens inside the brain's synapses. Indeed, modeling just one individual synapse requires the following to happen in the machinery: The synapse's state—how likely it is to pass on a signal-like input from a neuron, which is the major factor in how strong the association is between any two neurons—is in a location in main memory. To change that state, the processor must package an electronic signal for transfer over the main bus. That signal must travel between 2 and 10 centimeters to reach the physical memory and then must be unpackaged to actually access the desired memory location.

Now multiply that sequence by up to 8000 synapses—as much as a single rat neuron might have. Then multiply that by the number of neurons in the brain you're emulating—billions. Congratulations! You've just modeled an entire *millisecond* of brain activity.

A biological brain is able to quickly execute this massive simultaneous information orgy—and do it in a small package—because it has evolved a number of stupendous shortcuts. Here's what happens in a brain: Neuron 1 spits out an impulse, and the resultant information is sent down the axon to the synapse of its target, Neuron 2. The synapse of Neuron 2, having stored its own state locally, evaluates the importance of the information coming from Neuron 1 by integrat-

The Great Brain Race

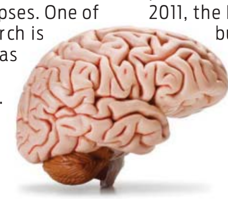
BLUE BRAIN: In 2005, Henry Markram and his team of neuroscientists and computer scientists at the École Polytechnique Fédérale de Lausanne, in Switzerland, use an IBM supercomputer to simulate one square centimeter of cerebral cortex.

C2: In 2009, IBM Almaden, in California, builds a cortical simulator on Dawn, a Blue Gene/P supercomputer at Lawrence Livermore National Laboratory. Integrating data from the fields of computation, communication, and neuroscience, the C2 simulator re-creates 1 billion neurons connected by 10 trillion individual synapses, or about the amount found in a small mammal.

NEUROGRID: Kwabena Boahen at Stanford is developing a silicon chip that can be used to simulate the dynamics and learning of several hundreds of thousands of neurons and a few billion synapses. One of the goals of this research is to build artificial retinas to be used as medical implants for the blind.

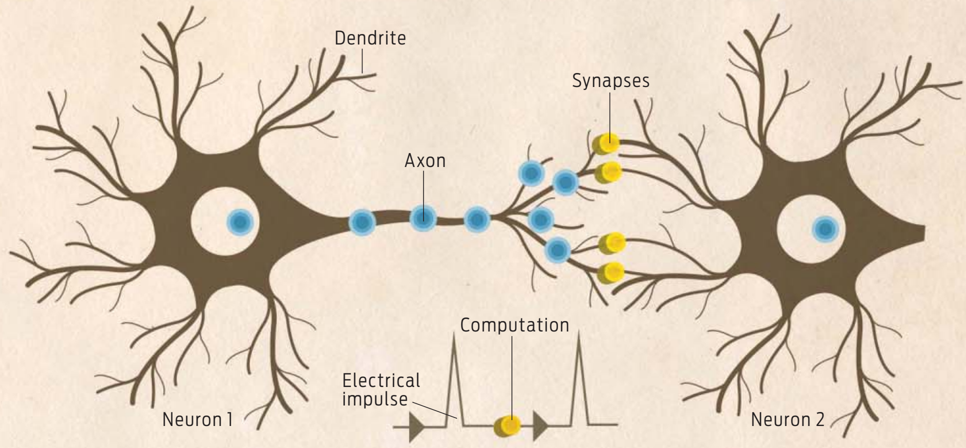
IFAT 4G: At Johns Hopkins University, Ralph Etienne-Cummings's fourth-generation system, the Integrate and Fire Array Transceiver, will consist of over 60 000 neurons with 120 million synaptic connections. An earlier version of the chip has been used to implement a visual cortex model for object recognition.

BRAINSCALES: In the European Union's neuromorphic chip program, called Fast Analog Computing with Emergent Transient States (FACETS), more than 100 computer scientists, engineers, and neuroscientists worked on a chip that exploits the concepts experimentally observed in biological nervous systems. The non–von Neumann hardware included a complex neuron model with up to 16 000 synaptic inputs per neuron. Starting in January 2011, the BrainScaleS project will build on the research undertaken in FACETS.

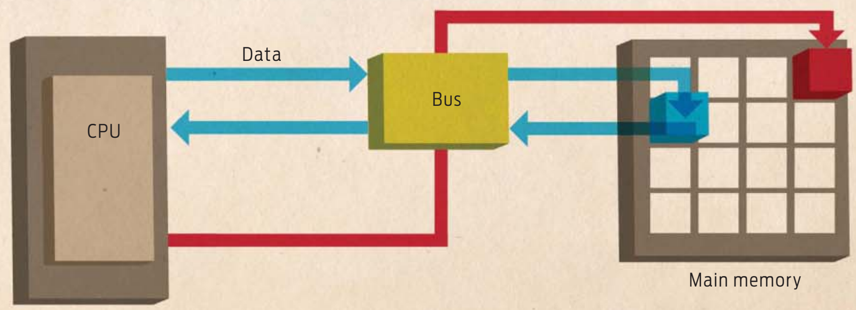


Hardware vs. Wetware To understand the difference between the architecture of the brain and a standard computer, compare the path of a hypothetical bit of data in a brain with that in a brain simulation.

BRAIN In the mammalian brain, storage and computation happen at the same time and in the same place. Neuron 1 sends a signal down the axon to Neuron 2. The synapse of Neuron 2 evaluates the importance of the information coming from Neuron 1 by contrasting it with its own previous state and the strength of its connection to Neuron 1. Then, these two pieces of information—the information from Neuron 1 and the state of Neuron 2's synapse—flow toward the body of Neuron 2 over the dendrites. By the time that information reaches the body of Neuron 2, there is only a single value—all computation has already taken place during the information transfer.



COMPUTER On a computer, the memory and processor are physically separated—a significant physical distance separates the areas where the data is stored from the areas where it is manipulated. Modeling just a single synapse requires the following to happen in the machinery: The synapse's state is in a location in main memory. To change that state, a signal must originate somewhere on the processor, travel to the edge of the processor, be packaged for transfer over the main bus, travel between 2 and 10 centimeters to reach the physical memory, and then be unpackaged to actually access the desired memory location. Multiplying that sequence by up to 8000 synapses—as many as in a single rat neuron—and then again by the brain's billions of neurons yields a single millisecond of brain activity.



ing it with its own previous state and the strength of its connection to Neuron 1. Then, these two pieces of information—the information from Neuron 1 and the state of Neuron 2's synapse—flow toward the body of Neuron 2 over the dendrites. And here is the important part: By the time that information reaches the body of Neuron 2, there is only a single value—*all processing has already taken place during the information transfer*. There is never any need for the brain to take information out of one neuron, spend time processing it, and then return it to a different set of neurons. Instead, in the mammalian brain, storage and processing happen at the same time and in the same place.

That difference is the main reason the human brain can run on the same power budget as a 20-watt lightbulb. But reproducing the brain's functionality on even the most advanced supercomputers would require a dedicated power plant. To be sure, locality isn't the only difference. The brain has some brilliantly efficient components that we just can't reproduce yet. Most crucially, brains can operate at around 100 millivolts. Complementary metal-oxide-semiconductor logic circuits, however, require a much higher voltage to function properly (close to 1 volt), and the higher operating voltage means that more power is expended in transmitting the signal over wires.

Now, replicating the structure we've described above is not totally impossible with today's silicon technology. A true artificial intelligence *could* hypothetically run on conventional hardware, but it would be fantastically inefficient. Inefficient hardware won't stop us from running neuromorphic algorithms (such as machine vision), but we would need an entire massive cluster of high-performance graphics processing units (GPUs) to handle the parallel computations, which would also come with the power requirements of a midwestern college town.

So how do you build something that has an architecture like the brain's? Here's DARPA's gambit: Change your architecture to merge memory and computation. The memristor is the best technology out there for the task. That's because the memristor is the first memory technology with enough power efficiency and density to rival biological computation. With these devices, we are confident we can build an AI that can approximate the size and power requirements of a mammal's brain.

Partly to avoid the folly of trying to coax intelligence from fundamentally dumb hardware, DARPA launched a program called SyNAPSE (Systems of Neuromorphic Adaptive Plastic Scalable Electronics) in 2008. The timing was good. That year, HP Labs had created a functioning memristor, a device hailed as the fourth fundamental electronic component, after the resistor, capacitor, and inductor. The concept wasn't new. In 1971, professor Leon Chua of the University of California, Berkeley, reasoned that a memristor would behave like a resistor with a conductance that changed as a function of its internal state and the voltage applied. In other words, because a memristor could remember how much current had gone through it, it could work as an essentially nonvolatile memory. And sure enough, Korean dynamic RAM giant Hynix Semiconductor made a splash recently when it chose the device as a possible foundation for its next-generation memory. But because memristors can remember their past state without using any power, their biggest potential all along has been as a realistic analogue to synapses in brains.

Here's why. A memristor is a two-terminal device whose resistance changes depending on the amount, direction, and duration of voltage that's applied to it. But here's the really interesting thing about a memristor: Whatever its past state, or resistance, it freezes that state until another voltage is applied to change it. Maintaining that state requires no power. That's different from a dynamic RAM cell, which requires regular charge to maintain its state. The upshot is that thousands of memristors could substitute for massive banks of power-hogging memory. Just to be clear, the memristor is not magic—its memristive state does decay over time. That decay can take hours or centuries depending on the material, and stability must often be traded for energy requirements—which is one of the major research reasons memristors aren't flooding the market yet.

Physically, a memristor is just an oxide junction between two perpendicular metal wires. The generic memristor can be thought of as a nanosize sandwich—the bread is the intersection of the two crossing wires. Between the "bread" slices is an oxide; charge-carrying bubbles of oxygen move through that oxide and can be pushed up and down through the material to determine the state—the last resistance—across the memristor. This resistance state is what freezes when the power is cut. Recent DARPA-sponsored work at HP has yielded more complex memristors, so this description is necessarily a bit generic. The important thing to recall is that the memristor's "state" can be considered analogous to the state of the synapse that we mentioned earlier: The state of the synapse depends how closely any two neurons are linked, which is a key part of the mammalian ability to learn new information.

The architecture of the brain-inspired microprocessor under development at HP Labs can be thought of as a kind of memristor-based multicore chip [see illustration, "MoNETA: A Mind Made of Memristors"]. Nowadays, high-end microprocessors all have multiple cores, or processing units. But instead of the eight or so cores typical of such a microprocessor, the HP hardware will contain hundreds of simple, garden-variety silicon processing cores, and each of these will have its own ultradense thicket of memristor lattices.

Each silicon core is directly connected to its own immediately accessible megacache made up of millions of memristors, meaning that every single core has its own private massive bank of memory. Memristors are incredibly tiny, even by the standards of today's semiconductor transistors: HP senior fellow Stan Williams claims that with advances in fabrication processes for stacking many crossbars on a single chip, within a couple of decades it will be possible to build a nonvolatile memristor-based memory with a petabit (a quadrillion bits) per square centimeter.

Though memristors are dense, cheap, and tiny, they also have a high failure rate at present, characteristics that bear an intriguing resemblance to the brain's synapses. It means that the architecture must by definition tolerate defects in individual circuitry, much the way brains gracefully degrade their performance as synapses are lost, without sudden system failure.

Basically, memristors bring data close to computation, the way biological systems do, and they use very little power to store that information, just as the brain does. For a comparable function, the new hardware will use two to three orders of magnitude less power than Nvidia's Fermi-class GPU. For the first time we will begin to bridge the main divide between biological computation and traditional computation. The use of the memristor addresses the basic hardware challenges of neuromorphic computing: the need to simultaneously move and manipulate data, thereby drastically cutting power consumption and space. You might think that to achieve processing that's more like thinking than computation would require more than just new hardware—it would also require new software. You'd be wrong, but in a way that might surprise you.

Basically, without this paradigm shift in hardware architecture, you couldn't even think about building MoNETA.

To build a brain, you need to throw away the conceit of separate hardware and software because the brain doesn't work that way. In the brain it's all just wetware. If you really wanted to replicate a mammalian brain, software and hardware would need to be inextricable. We have no idea how to build such a system at the moment, but the memristor has allowed us to take a big step closer by approximating the biological form factor: hardware that can be both small and ultralow power.

Where HP is taking care of the hardware component of the neuromorphic processor, we are building the software—the brain models that will populate the hardware. Our biological algorithms will create this entity: MoNETA. Think of MoNETA as the application software that does the recognizing, reasoning, and learning. HP chose our team at Boston University to build it because of our experience at the Center of Excellence for Learning in Education, Science, and Technology (CELEST), funded by the National Science Foundation. At CELEST, computational modelers, neuroscientists, psychologists, and engineers collaborate with researchers from Harvard, MIT, Brandeis, and BU's own department of cognitive and neural systems. CELEST was established to study basic principles of how the brain plans, organizes, communicates, and remembers.

To allow the brain models and the neuromorphic hardware to interact, HP built a kind of special-purpose operating system called Cog Ex Machina. Cog, built by HP principal investigator Greg Snider, lets system designers interact with the underlying hardware to do neuromorphic computation. Neuromorphic computation means computation that can be divided up between hardware that processes like the body of a neuron and hardware that processes the way dendrites and axons do.

The two kinds of cores deal with processing in fundamentally different ways. A "neuron-type" CPU architecture makes this core flexible, letting it handle any operation you throw at it. In that way, its

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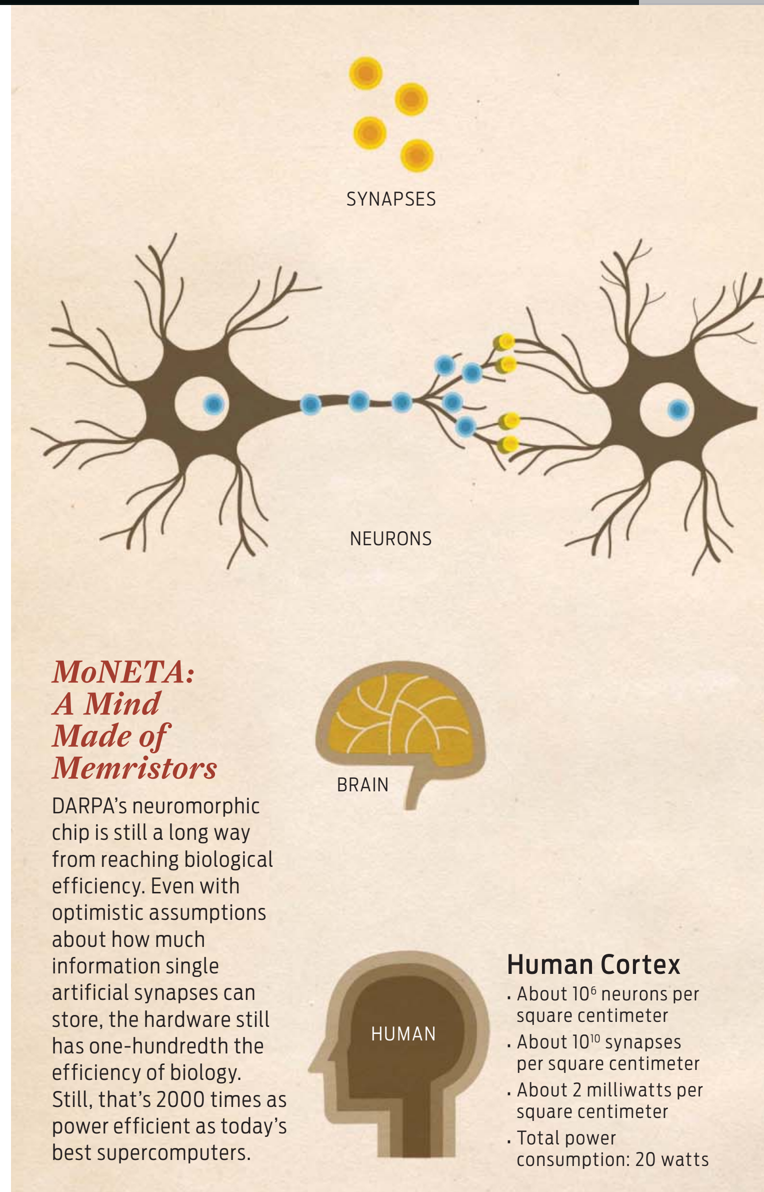
characteristics resemble those of the neuron. But the trade-off is that the core sucks up a lot of power, so like neurons, these elements should make up only a small percentage of the system.

A "dendritic" core works more like a GPU, an inexpensive and high-performance microprocessor. Like a dendrite, a GPU has a rigid architecture that is optimized for only a specific kind of computation—in this case, the complicated linear algebra operations that approximate what happens inside a dendrite. Because GPUs are optimized for parallel computation, we can use them to approximate the distributed computation that dendrites carry out. But there's a cost to using these, too: GPU cores perform only a limited set of operations. The dendrite cores in the final DARPA hardware will be much less flexible than neuron cores, but they will store extraordinary amounts of state information in their massive memristor-based memory banks, and like the tendrils of neurons, they will make up the vast bulk of the system's computational elements. Memristors, finally, will act as the synapses that mediate the information transfer between the dendrites and axons of different neurons. For a programmer, taking full advantage of a machine like this—with its two different core types and complicated memory-storage overlay—is tremendously challenging, because the problems need to be properly partitioned across those two radically different types of processors. Thanks to Cog, we computational neuroscientists can forget about the hardware and focus on developing the soul inside the machine.

MoNETA WILL BE A general-purpose mammalian-type intelligence, an artificial, generic creature known as an animat. With the DARPA hardware, we think we will be able to fit this level of intelligence into a shoebox.

The key feature distinguishing MoNETA from other AIs is that it won't have to be explicitly programmed. We are engineering MoNETA to be as adaptable and efficient as a mammal's brain. We intend to set it loose on a variety of situations, and it will learn dynamically.



MoNETA: A Mind Made of Memristors

DARPA's neuromorphic chip is still a long way from reaching biological efficiency. Even with optimistic assumptions about how much information single artificial synapses can store, the hardware still has one-hundredth the efficiency of biology. Still, that's 2000 times as power efficient as today's best supercomputers.

Biological intelligence is the result of the coordinated action of many highly interconnected and plastic brain areas. Most prior research has focused on modeling those individual parts of the brain. The results, while impressive in some cases, have been a piecemeal assortment of experiments, theories, and models that each nicely describes the architecture and function of a single brain area and its contribution to perception, emotion, and action. But if you tried to stitch those findings together, you would more likely end up with a nonfunctioning Frankenstein's monster than anything like a mammalian intelligence.

Truly general-purpose intelligence can emerge only when everything happens all at once: In intelligent creatures like our humble rat, all perception (including auditory and visual inputs, or the brain areas responsible for the generation of fine finger movements), emotion, actions, and reactions combine and interact to guide behavior. Perceiving without action, emotion, higher reasoning, and learning would not only fail to lead to a general purpose AI, it wouldn't even pass a commonsense Turing test.

Creating this grail-like unified architecture has been precluded by several practical limitations. The most important is the lack of a unified theory of the brain. But the creation of large centers such as CELEST has advanced our understanding of what key aspects of biological intelligence might be applicable to our task of building a general-purpose AI.

HOW WILL WE KNOW we've succeeded? How will we know that all this effort and new hardware and new software have yielded what we want—an artificial intelligence? We'll know we have successfully built an animat when we are able to motivate MoNETA to run, swim, and find food dynamically, without being programmed explicitly to do so.

It should learn throughout its lifetime without needing constant reprogramming or needing to be told a priori what is good for it, and what is bad. This is a true challenge for traditional AI: It is not possible to preprogram a lifetime of knowledge into a virtual or robotic animat. Such wisdom has to be learned from the interaction between a brain—with its large (but not infinite) number of synapses that store memories—and an environment that is constantly changing and dense with information.

The animat will learn about objects in its environment, navigate to reach its goals, and avoid dangers without the need for us to program specific objects or behaviors. Such an ability comes standard-issue in mammals, because our brains are

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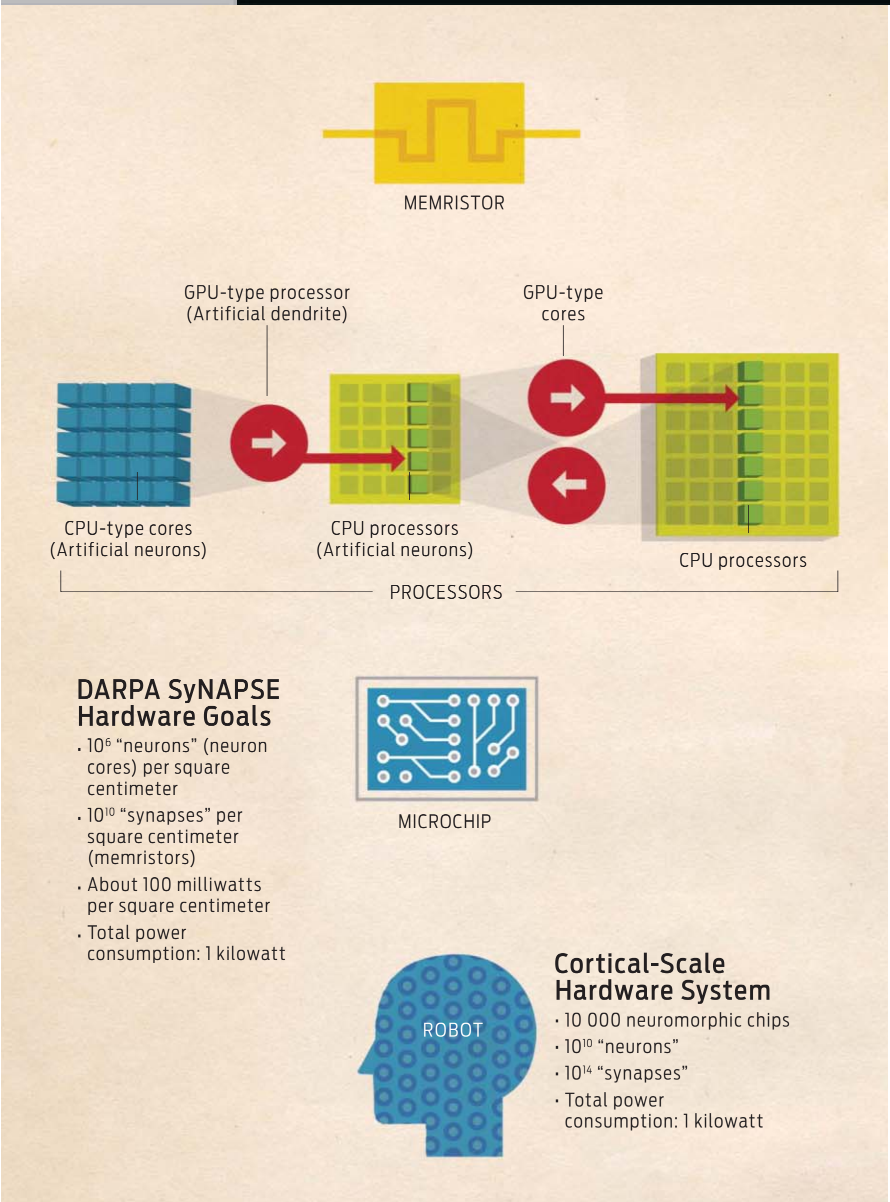


plastic throughout our lives. We learn to recognize new people and places, and we acquire new skills without being told to do so. MoNETA will need to do the same.

We will test our animat in a classic trial called the Morris water navigation task. In this experiment, neuroscientists teach a rat to swim through a water maze, using visual cues, to a submerged platform that the rat can't see. That task might seem simple, but it's anything but. To get to the platform, the rat must use many stupendously sophisticated brain areas that synchronize vision, touch, spatial navigation, emotions, intentions, planning, and motor commands. Neuroscientists have studied the water maze task at great length, so we know a great deal about how a rat's anatomy and physiology react to the task. If we can train the animat to negotiate this maze, we'll be confident that we have taken an important first step toward simulating a mammalian intelligence.

By the middle of next year, our researchers will be working with thousands of candidate animats at once, all with slight variations in their brain architectures. Playing intelligent designers, we'll cull the best ones from the bunch and keep tweaking them until they unquestionably master tasks like the water maze and other, progressively harder experiments. We'll watch each of these simulated animats interacting with its environment and evolving like a natural organism. We expect to eventually find the "cocktail" of brain areas and connections that achieves autonomous intelligent behavior. We will then incorporate those elements into a memristor-based neural-processing chip. Once that chip is manufactured, we will build it into robotic platforms that venture into the real world. Robot companions for the elderly, robots to be sent to Mars to forage autonomously, and unmanned aerial vehicles will be just the beginning.

Will these chips "experience" vision and emotions by simulating and appropriately connecting the brain areas known to be involved in the subjective experience associated with them? It's too soon to say. However, our goal is not to replicate subjective experience—consciousness—in a chip but rather to build functional machines that can behave intelligently in complex environments. In other words, the idea is to make machines that behave as if they are intelligent, emotionally biased, and motivated, *without* the constraint that they are actually aware of these feelings, thoughts, and motivations.

NEUROMORPHIC CHIPS won't just power niche AI applications. The architectural lessons we learn here will revolutionize all future CPUs. The fact is, conventional computers will just not get significantly more powerful unless they move to a more parallel and locality-driven architecture. While neuromorphic chips will first supplement today's CPUs, soon their sheer power will overwhelm that of today's computer architectures.

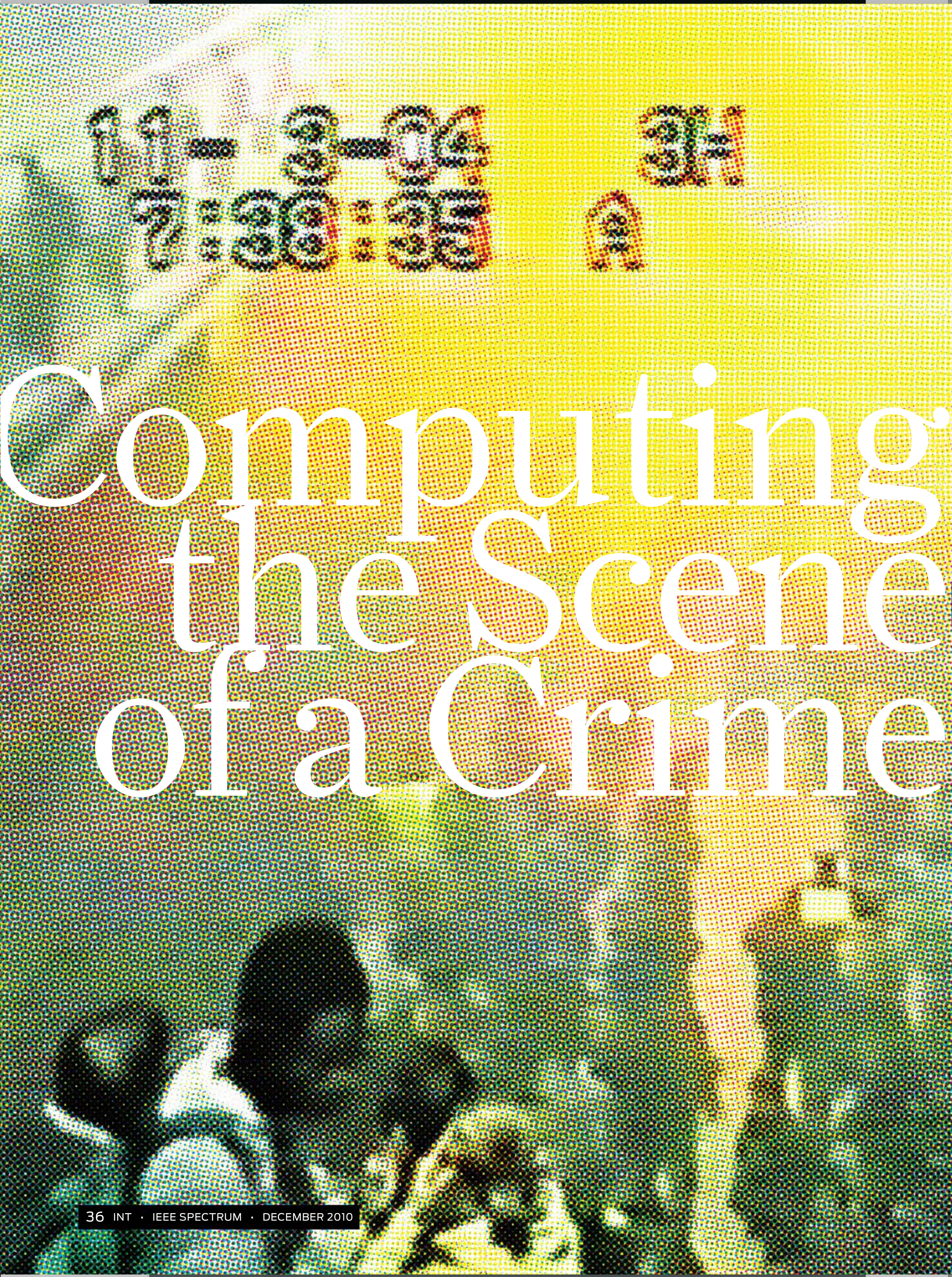
The semiconductor industry's relentless push to focus on smaller and smaller transistors will soon mean transistors have higher failure rates. This year, the state of the art is 22-nanometer feature sizes. By 2018, that number will have shrunk to 12 nm, at which point atomic processes will interfere with transistor function; in other words, they will become increasingly unreliable. Companies like Intel, Hynix, and of course HP are putting a lot of resources into finding ways to rely on these unreliable future devices. Neuromorphic computation will allow that to happen on both memristors and transistors.

It won't be long until all multicore chips integrate a dense, low-power memory with their CMOS cores. It's just common sense.

Our prediction? Neuromorphic chips will eventually come in as many flavors as there are brain designs in nature: fruit fly, earthworm, rat, and human. All our chips will have brains. ❑

TELL US WHAT YOU THINK at http://spectrum.ieee.org/moneta1210

Computing the Scene of a Crime



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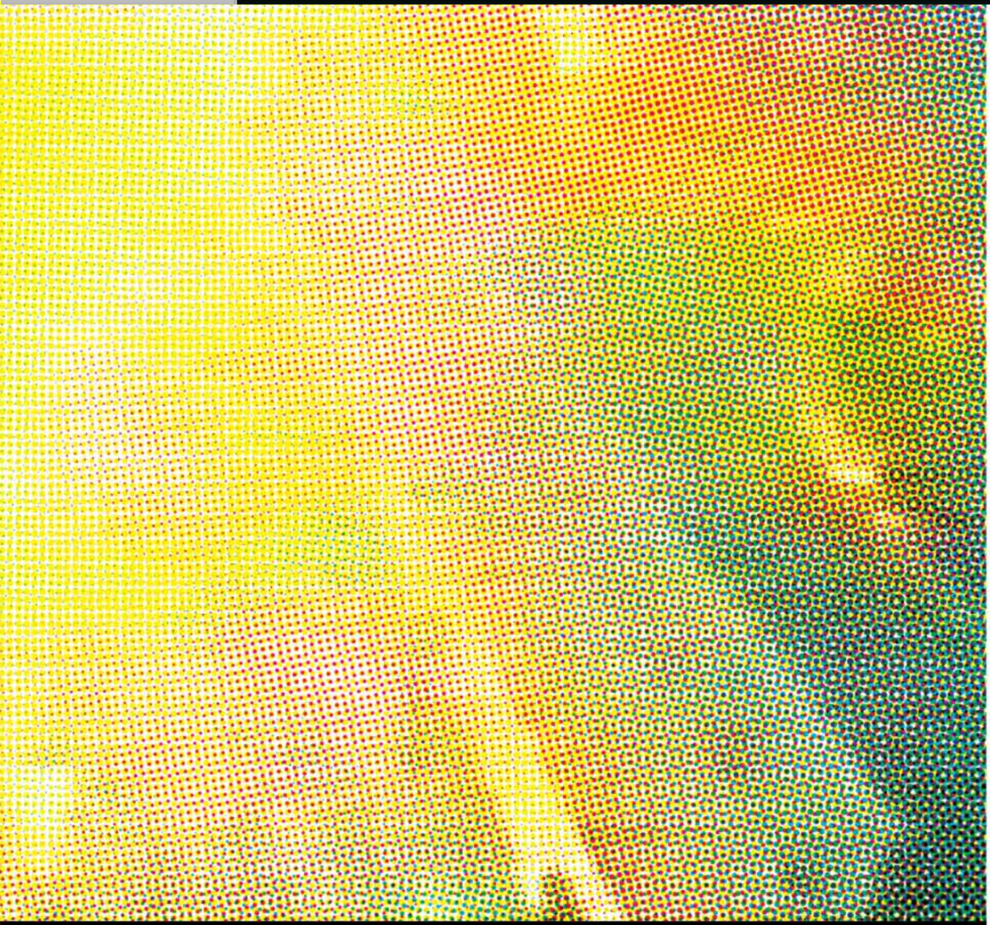


COMPUTATIONAL METHODS CAN REDUCE THE BIAS INHERENT IN TRADITIONAL CRIMINAL FORENSICS

FBI FILE FINGERPRINT
Brandon Mayfield, 1984

ON 6 MAY 2004, a Portland, Oregon, lawyer named Brandon Mayfield was arrested for his alleged involvement in the terrorist bombings of four commuter trains in Madrid. The attacks killed 191 people and injured 2000 others. But Mayfield had never been to Spain, and his passport at the time was expired. The sole evidence against him was a partial fingerprint found on a plastic bag in a van used by the bombers. The FBI's Integrated Automated Fingerprint Identification System had identified Mayfield as a possible match, and three FBI fingerprint experts as well as an outside analyst confirmed the identification.

By SARGUR N. SRIHARI

TERROR ERROR: Closed-circuit television captured this image just seconds after three bombs exploded at Madrid's Atocha train station on 11 March 2004. The FBI claimed that a fingerprint at one of the bomb sites was that of U.S. citizen Brandon Mayfield but later retracted its accusation.

IMAGE: EFE/EL PAIS/AP PHOTO

[redacted]

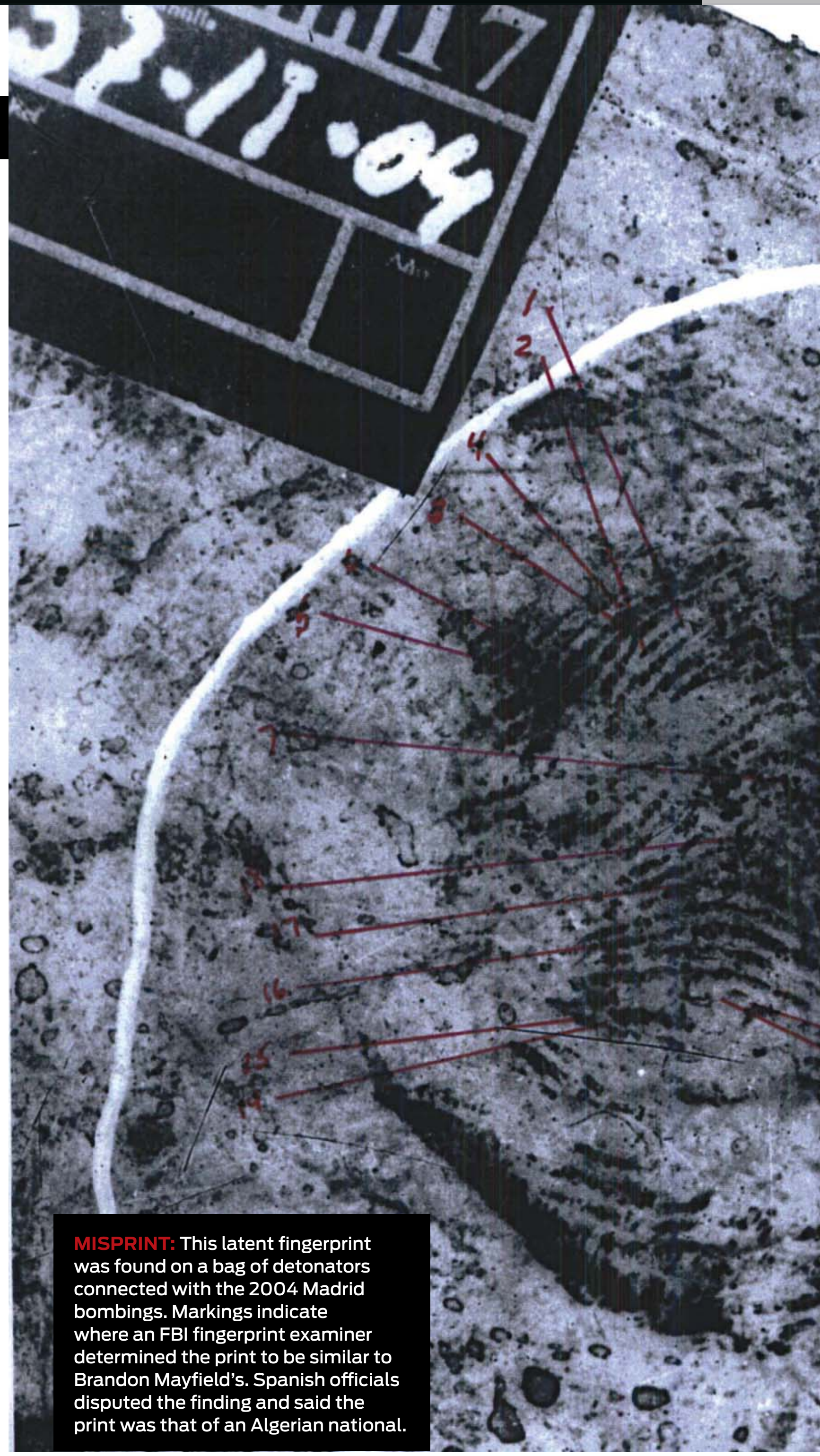
The analysts knew that Mayfield had converted to Islam, was married to an Egyptian woman, and had once represented a man in a child custody case who later turned out to be part of a jihadist group. That information swayed the FBI inquiry in Mayfield's direction.

Spanish authorities, however, argued that the fingerprint belonged not to Mayfield but to an Algerian with a criminal record, Spanish residency, and terrorist links. They were right. It took almost three weeks from his arrest, but Mayfield was cleared of the charges and released from federal custody. The U.S. government eventually agreed to pay him US $2 million for the mistake and issued a formal apology.

Such high-profile cases grab the headlines and our attention, but they also point to an underlying problem with fingerprints—and with shoe prints, handwriting, and nearly every other form of classical forensics data. "The fact is that many forensic tests...have never been exposed to stringent scientific scrutiny," a committee convened by the U.S. National Academy of Sciences concluded last year. One of the main problems with forensics evidence is that it must be analyzed and interpreted by a person, whose own theory of the crime can introduce a bias in the results. There can also be significant uncertainty in the analyst's conclusions, but oftentimes that uncertainty is never quantified or conveyed to judges and juries.

And yet, these traditional forms of forensics evidence can be very helpful, provided they can be looked at objectively and the uncertainty of the results can be measured and properly explained. The relatively new field of computational forensics has sprung up to address those needs.

Computational forensics is not yet mainstream. But lots of research goes on in academic settings, such as at my own lab at the State University of New York at Buffalo, and eventually the courts may allow these techniques to be applied in criminal trials. Clearly, any method that can improve the analysis of evidence would be a good thing.

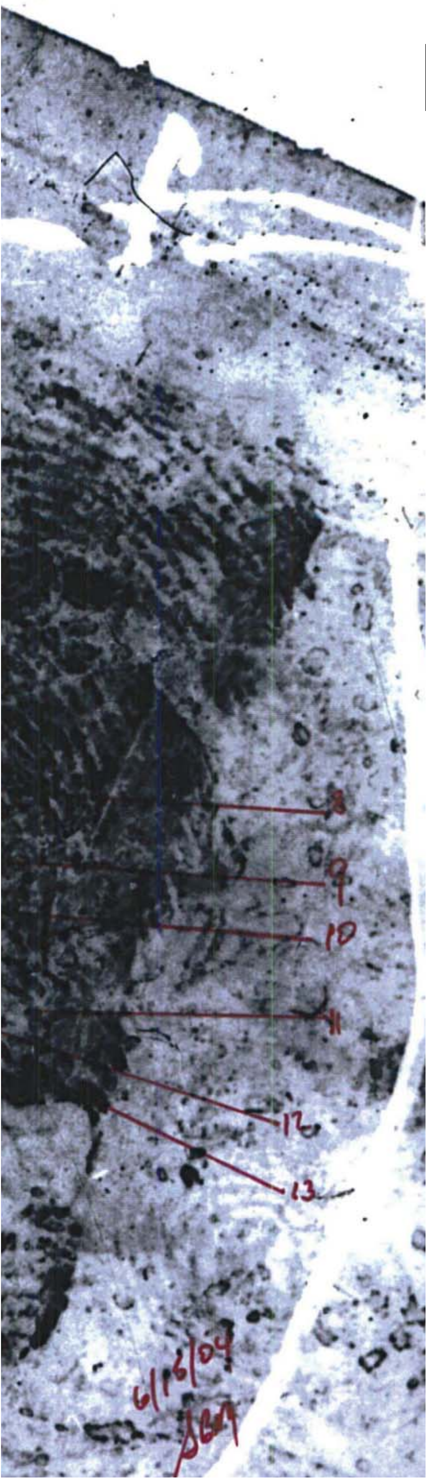


MISPRINT: This latent fingerprint was found on a bag of detonators connected with the 2004 Madrid bombings. Markings indicate where an FBI fingerprint examiner determined the print to be similar to Brandon Mayfield's. Spanish officials disputed the finding and said the print was that of an Algerian national.

U.S. DEPARTMENT OF JUSTICE

On the popular television series "C.S.I." and its spin-offs, attractive forensics experts speedily uncover long trails of evidence that point unfailingly to the true villains. In the real world, crime scene investigations are rarely so cut and dried (and the people carrying them out are rarely so glamorous). More often, forensics experts must rely on a few murky clues, none of which is definitive in itself. Even then, as the Brandon Mayfield case revealed, the biases of the analysts can lead to erroneous conclusions.

To appreciate how computational methods could avoid such blunders, it's helpful to understand how forensics data are used. In general, a forensics investigation attempts to match crime scene evidence with a known source. The first step is an analysis of the evidence, followed by a comparison of the evidence with data from known sources, and finally an independent verification of the results.



FBI FILE FINGERPRINT Madrid latent print, 15 June 2004

The type of evidence determines how exactly this process unfolds. An incredibly wide variety of classical forensics data exists: impression patterns (such as latent fingerprints, shoe prints, and tire treads), nonimpression patterns (for example, bloodstains and speech), trace evidence (including paint, dust, and pollen), biological evidence (such as DNA and hair), and toxicological evidence (including drugs or alcohol in the victim's bloodstream).

Then there's the whole burgeoning field of digital forensics, which involves the use of data extracted from personal computers, cellphones, digital cameras, and the like. [For more information on these topics, see *IEEE Spectrum*, "Cellphone Crime Solvers," July 2010, and "Seeing Is Not Believing," August 2009.]

During two years of deliberation by the National Academy's forensic science committee (of which I was a member), a troubling picture emerged. A large part of current forensics practice is skill and art rather than science, and the influences present in a typical law-enforcement setting are not conducive to doing the best science. Also, many of the methods have never been scientifically validated. And the wide variation in forensic data often makes interpretation exceedingly difficult.

Among all the classical forensics methods, the committee concluded, only DNA analysis has been shown to be scientifically rigorous [see sidebar, "The DNA Difference"]. But committee members identified several areas where the greater use of computers and automation could eliminate bias and minimize error.

Some degree of automation already exists. In the Madrid bombing case, FBI analysts first examined the crime scene fingerprint by hand. Then they ran the print through the bureau's fingerprint database, which with some 400 million records from 66 million people is said to be the largest biometric database in the world. The search produced 20 matches, on which the analysts did side-by-side comparisons with the crime scene print. Eventually they deemed Mayfield's the closest match, with 15 points of similarity. (Mayfield's prints dated from 1984, when as a teenager in Kansas he had been arrested for burglary.) It's more or less like using a search engine such as Google: You rely on the search engine's algorithms to return results matching your query, but invariably you have to go through the list to find what you're looking for. The main difference, of course, is that in a criminal investigation the stakes are much higher.

So HOW might greater automation of classical forensics techniques help? New algorithms and software could

The DNA Difference

In stark contrast to the other forms of forensics evidence, DNA is considered extremely reliable, with very low error rates. Since 1989, DNA evidence has led to more than 200 exonerations, most involving wrongful convictions for rape and murder.

What accounts for this difference? In any forensics analysis, there are two basic issues: rarity and similarity. Let's say that the person who committed a crime is 220 centimeters tall. That's a fairly rare height for a human, so if you find a suspect of exactly that height, you'd consider that significant. But how sure are you that the perpetrator is 220 cm tall, and not 205 or 240 cm? Suddenly, the striking similarity in the data isn't quite so striking.

DNA analysis, which evolved serendipitously from genomic research, deals only with rarity. It starts with the fact that the human genome consists of 3 billion base pairs of nucleotides, which are stored within each cell's nucleus as well as in certain organelles outside the nucleus. Only about 1.5 percent of the nuclear genome contains useful information. The rest, known as junk DNA, has no survival function but is useful for identification because its sequence of base pairs varies from person to person.

A DNA profile is constructed by looking at the specific arrangement of a few hundred base pairs at 13 locations within a suspect's genome and then comparing the results with a known sample gathered at the crime scene. The entire process is automated. For each location, the probability of a random correspondence, or PRC—that is, the odds that two randomly chosen samples will have the same measured value—is 0.1. Therefore, the average PRC for all 13 locations is 1 in 10 trillion. Other forensic techniques may claim PRCs that low, but human examiners must get involved in those cases, and there is still too much uncertainty and bias in how they interpret the data.

Given the low error rate with DNA, why isn't it used in every criminal investigation? Because DNA is recovered from only about 10 percent of crime scenes. What's more, the mere presence of a suspect's DNA at the scene says nothing about how it got there. And jurors may not be swayed by DNA alone; often they want additional evidence that they can more easily comprehend, such as fingerprints, shoe prints, or handwriting. —*S.N.S.*

improve things in a number of ways. One important area is to quantify the chance that the evidence is unique by applying various probability models.

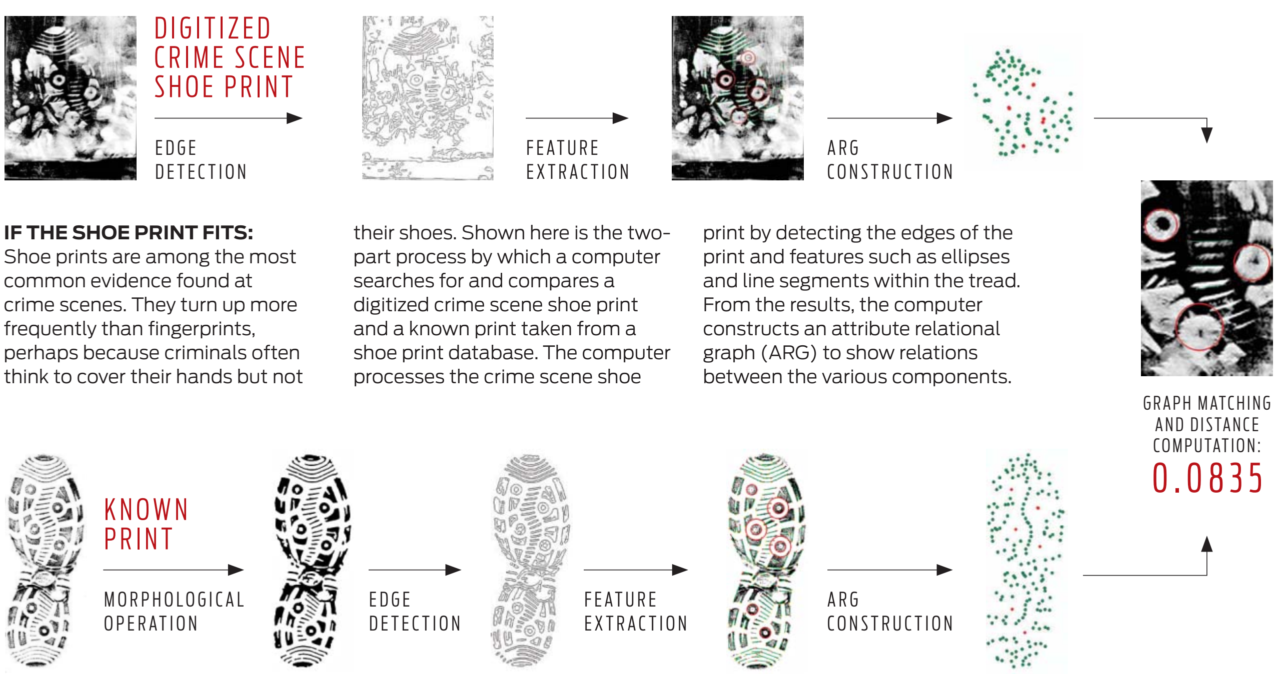
Let's look at the uniqueness problem as it applies to fingerprints. As children, we learn that no two people have the same fingerprints. That may indeed be true, but in a sufficiently large pool of people, the likelihood of two of them having very similar fingerprints is quite high. Beginning in the 1800s, scientists began looking for distinct features within the ridges of fingerprints—such as whorls, arches, single loops, and double loops—that would help distinguish one person's prints from another's. However, such broad features occur with surprising frequency. Left loops, for example, are found in 30 percent of all fingerprints, and right loops are nearly as common. So fingerprint analysts also look at more detailed features, known as minutiae, such as the locations and directions of ridge endings and bifurcations.

Fingerprint-matching algorithms mostly search for and compare minutiae rather than the larger features, because minutiae are less common and yet are still stable and can be reliably extracted and compared by computer. So the key question in quantifying the individuality of fingerprint evidence is, what are the odds that two randomly chosen samples will have a high degree of similarity?

Using statistical modeling based on the frequencies of specific minutiae in the population, the theoretical probability that a random pair of fingerprints will exhibit a match of, say, 12 of 36 minutiae works out to 1 in 100 billion. While that sounds extraordinary, keep in mind that there is almost always uncertainty in the quality of the minutiae data. For instance, a smudged or partial fingerprint can lead a human analyst (or a computer, for that matter) to flag a similarity where none may in fact exist. Also, more research is needed to determine the exact frequencies with which certain fingerprint features occur. At present, nobody really knows how likely it is for two people's prints to match closely or the extent to which trained fingerprint analysts can tell them apart. Indeed, experts sometimes disagree on what constitutes a match.

To address these issues, my research group and others are trying to figure out how to calculate the probability of one person's fingerprints randomly matching those of any other in a given population. That's a key thing to know. If a fingerprint found at the crime scene corresponds reasonably well to a print from the accused, the prosecution hypothesis is that they are from the same person, while the defense hypothesis is that they are from different people. With the right computational tools you can calculate two probability values, one for the prosecution hypothesis and one for the defense hypothesis. And the ratio of the former to the latter shows just how incriminating (or not) this evidence is.

COMPUTATIONAL FORENSICS can also be used to narrow down the range of possible matches against a database of cataloged patterns. To do that, you need a way to quantify the similarity between the



IF THE SHOE PRINT FITS: Shoe prints are among the most common evidence found at crime scenes. They turn up more frequently than fingerprints, perhaps because criminals often think to cover their hands but not their shoes. Shown here is the two-part process by which a computer searches for and compares a digitized crime scene shoe print and a known print taken from a shoe print database. The computer processes the crime scene shoe print by detecting the edges of the print and features such as ellipses and line segments within the tread. From the results, the computer constructs an attribute relational graph (ARG) to show relations between the various components.

The known shoe print is enhanced, and then, as with the crime scene print, its edges and features are detected and an ARG constructed. The two ARGs are then compared, resulting in a score ranging from 0 to 1, with 1 indicating a complete match and 0 indicating no similarity. The comparison can be done with each known print in the database, eventually resulting in a short list of prints that closely match the crime scene print.

CENTER OF EXCELLENCE FOR DOCUMENT ANALYSIS AND RECOGNITION/STATE UNIVERSITY OF NEW YORK AT BUFFALO query and each entry in the database. These similarity values are then used to rank the database entries and retrieve the closest ones for further comparison. Of course, the process becomes more complicated when the database contains millions or even hundreds of millions of entries. But then, computers are much better suited than people to such tedious and repetitive search tasks.

Here's how an automated database search could work with shoe prints, which are among the most common types of evidence found at crime scenes [see illustration, "If the Shoe Print Fits"]. The shoe print database may consist of photographs of the outsoles provided by shoe manufacturers or vendors. Each shoe print in the database is indexed using a feature vector or description, similar to those used in computer vision applications for representing elements in an image. For the shoe print, the feature description identifies the straight edges in the print and patterns such as ellipses, circles, or herringbones.

The query print taken from the crime scene is usually of much poorer quality. For example, the print may be nearly indistinguishable from the surface on which it was made, and so it first needs to be enhanced. One way to do this is with an image-processing technique known as intelligent thresholding, which automatically breaks up an image into its component segments and separates the foreground (the print) from the background (the surface). Once the shoe print has been enhanced, a corresponding feature description is extracted. The search algorithm then computes the similarity between the query and each database shoe print. Lastly, the database entries are ranked to reveal the closest matches.

Currently, forensics examiners who analyze shoe prints have no means of conducting such an automated search. The state of the art is a database package called SoleMate, developed by Foster & Freeman, in Evesham, England, and sold to law-enforcement agencies worldwide for about $7000. It works like this: The user renders onscreen a close approximation of the crime scene shoe print by selecting common features and locations—such as a star pattern near the big toe—from drop-down menus. SoleMate then compares the result to its database of more than 24 000 sports,

SEEN AT THE SCENE: Of all the footwear on the market, the Nike Air Force 1 sneaker is the most often encountered at U. S. crime scenes, turning up in about 17 percent of cases.
PHOTO: NIKE

work, and casual shoes, which it regularly updates using data from shoe companies. Clearly, though, having to redraw the shoe print is needlessly time-consuming. My team is currently working with Foster & Freeman on ways to automate its software.

Of course, fingerprints and shoe prints aren't the only kinds of evidence that could be evaluated automatically. For some cases, you might need to compare handwriting samples—to identify the source of a threat note, for instance.

Analyzing handwriting is less straightforward than fingerprint analysis, because a person's handwriting varies somewhat from day to day and can change dramatically over the course of years. Also, handwriting can be forged in a way that fingerprints and DNA cannot. Still, there are ways that computers can aid in handwriting comparisons.

A handwriting sample has global or macro features, such as line spacing and slant, as well as micro features like the shapes of letters and whole words. For a computer to be able to compare a handwritten paragraph, the sample must first be processed to extract individual lines of text, individual words within those lines, and individual letters and combinations of letters within those words.

From these basic components, the computer can quantify the features present in the sample, and a measure of similarity between it and that of a known sample can then be calculated. At present, there's no way to entirely automate this process, because tasks like the recognizing and isolating of individual letters are quite complex and better handled by humans than by machine.

But handwriting-recognition software continues to improve, as shown at the U.S. Postal Service, where 95 percent of all handwritten addresses can now be read by machine. In fact, forensic handwriting analysis builds directly on methods developed for recognizing postal addresses, and a commercially available forensics program called CEDAR-FOX incorporates work that my group did in this area. There are some key differences between the two applications, however. While both need to separate lines and words of text and recognize individual letter shapes, address recognition isn't really concerned with the handwriting differences between individuals, whereas in forensics it is these very differences that need to be captured. Even so, it seems only a matter of time before computers make greater inroads into handwriting forensics.

What computational forensics—or any forensics method, really—cannot do is determine whether a suspect did or did not commit the offense. That's a matter for a judge and jury to decide. At trial, the role of a forensics expert is to testify whether the profile drawn from the evidence matches that of the suspect or of an unrelated person. It's still common, though, for a lawyer to ask a forensics expert to speculate on matters further afield, such as the type of activity that might have led to the presence of the evidence at the crime scene. And some of those experts will freely render such opinions—but they shouldn't.

Will traditionally trained forensics examiners welcome the further incursion of computers into their work? I believe they will. Those I've met have been eager to learn about new technologies to improve what they do (even while I'm pointing out the shortcomings of their current practices). Likewise, those of us active in computational forensics pursue these techniques not solely for the intellectual challenge but because we firmly believe that our work will one day help to prevent the wrongful conviction and punishment of innocent people. Such injustices are tragedies, not only because those convicted suffer but also because the guilty remain at large. ❑

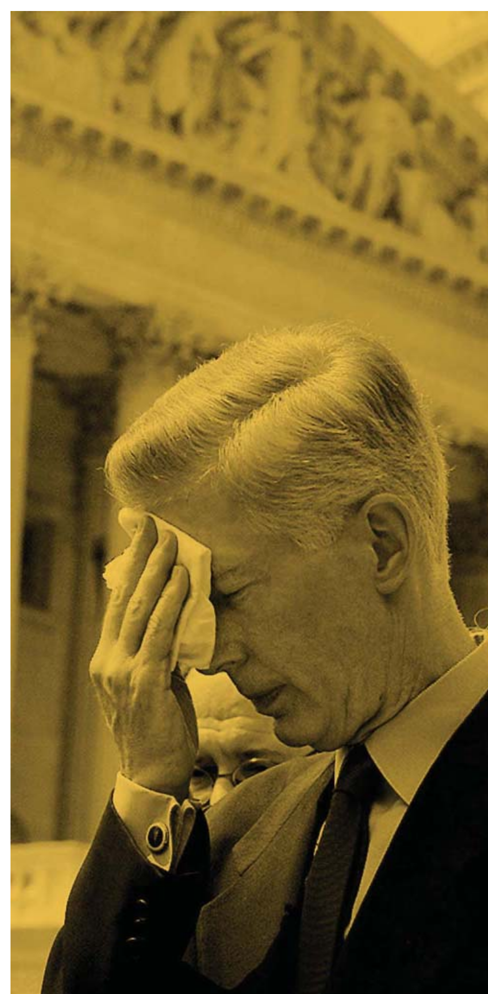
WRITE TO US at http://spectrum.ieee.org/crimeforensics1210

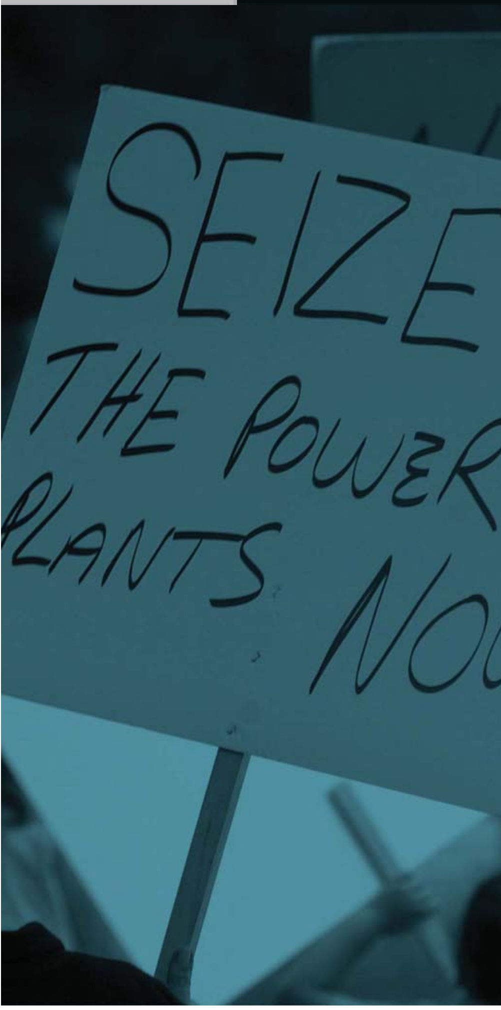
CALIFORNIA SCREAMIN': Los Angeles protesters [top left] show their anger over electricity shortages in June 2001. California Senator Barbara Boxer [top right] uses a chart to show wholesale electricity costs climbing in 2000 and 2001 and the suspicious timing of stock sales by Enron Corp.'s CEO, the late Kenneth Lay. California Governor Gray Davis [bottom left] wipes his brow after testifying to Congress in the summer of 2001 about the energy crisis his state was then facing. A worker monitoring California's power system [bottom right] shows his consternation two days before Gray Davis declares a state of emergency in January 2001.
PHOTOS, CLOCKWISE FROM TOP LEFT: DAVID McNEW/GETTY IMAGES; MIKE THEILER/AFP/GETTY IMAGES; JOE JASZEWSKI/LIAISON/GETTY IMAGES; STEPHEN JAFFE/AFP/GETTY IMAGES

How the Free Market Rocked the Grid

It led to higher rates and rolling blackouts, but it also opened the door to greener forms of electricity generation

By SETH BLUMSACK




SEIZE
THE POWER
PLANTS


KENNETH LAY'S
Wholesale Electricity Price
STOCK SALES $5,362,829
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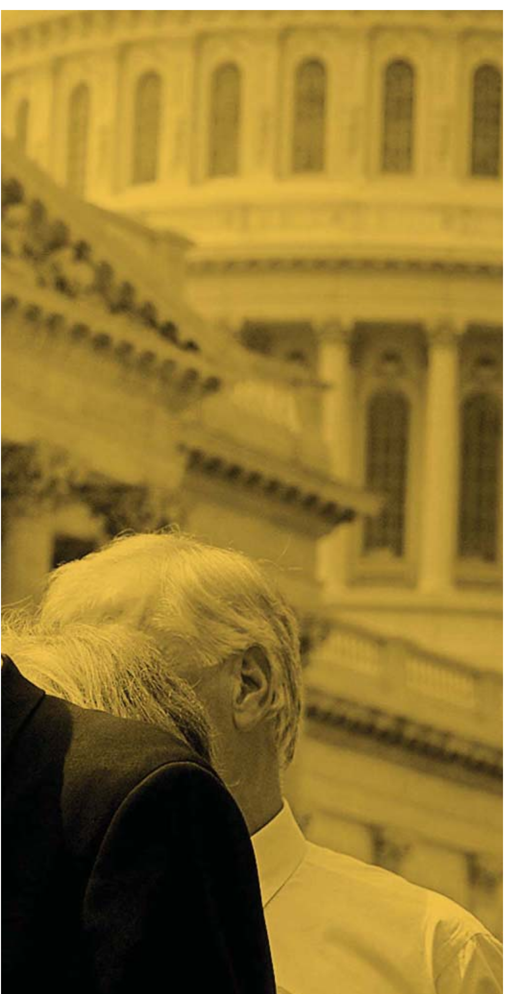

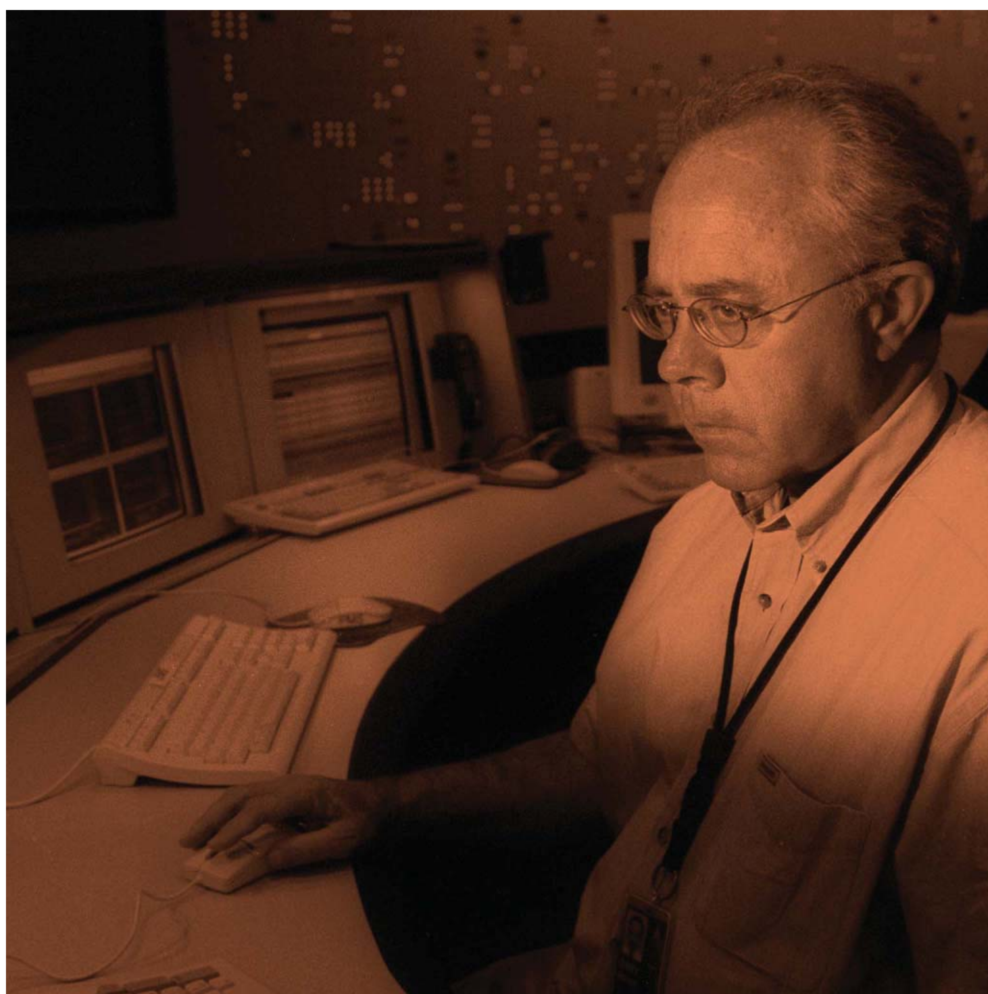

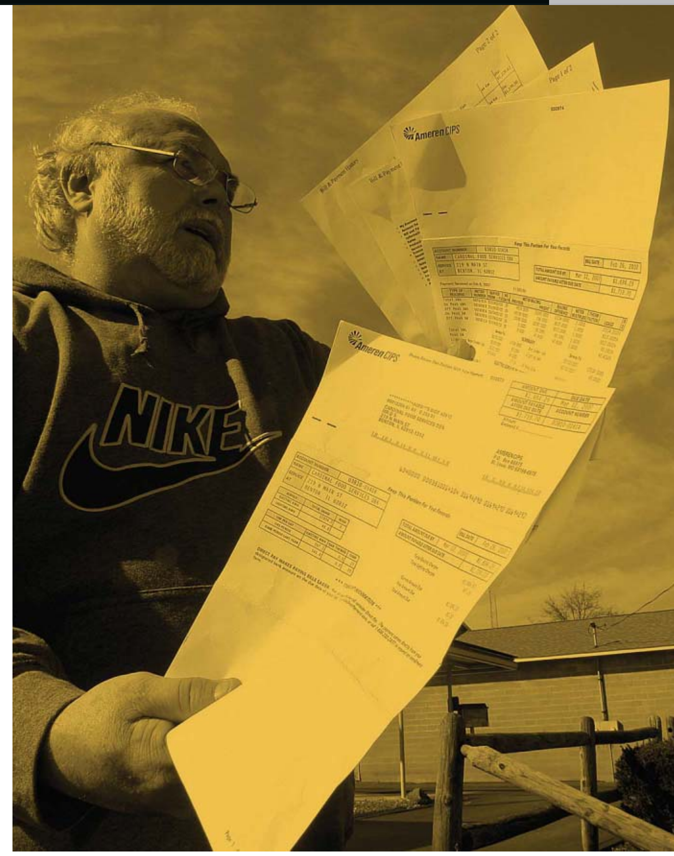

Most of us take for granted that the lights will work when we flip them on, without worrying too much about the staggeringly complex things needed to make that happen. Thank the engineers who designed and built the power grids for that—but don't thank them too much. Their main goal was reliability; keeping the cost of electricity down was less of a concern. That's in part why so many people in the United States complain about high electricity prices. Some armchair economists (and a quite a few real ones) have long argued that the solution is deregulation. After all, many other U.S. industries have been deregulated—take, for instance, oil, natural gas, or trucking—and greater competition in those sectors swiftly brought prices down. Why not electricity?

Such arguments were compelling enough to convince two dozen or so U.S. states to deregulate their electric industries. Most began in the mid-1990s, and problems emerged soon after, most famously in the rolling blackouts that Californians suffered through in the summer of 2000 and the months that followed. At the root of these troubles is the fact that free markets can be messy and volatile, something few took into account when deregulation began. But the consequences have since proved so chaotic that a quarter of these states have now suspended plans to revamp the way they manage their electric utilities, and few (if any) additional states are rushing to jump on the deregulation bandwagon.

The United States is far from being the only nation that has struggled with electricity deregulation. But the U.S. experience is worth exploring because it highlights many of the challenges that can arise when complex industries such as electric power generation and distribution are subject to competition.

Unlike many other nations grappling with electricity deregulation, the United States has never had one government-owned electric utility running the whole country. Instead, a patchwork of for-profit utilities, publicly owned municipal utilities, and electric cooperatives keeps the nation's lights on. The story of how that mixture has evolved over the last 128 years helps to explain why deregulation hasn't made electric power as cheap and plentiful as many had hoped.

The 1882 opening of Thomas Edison's Pearl Street generation station in New York City marks the birth of the American electric utility industry. That station produced low-voltage direct current, which had to be consumed close to the point of production, because sending it farther would have squandered most of the power as heat in the connecting wires.

Edison's approach prevailed for a while, with different companies scrambling to build neighborhood power stations. They were regulated only to the extent that their owners had to obtain licenses from local officials. Municipalities handed these licenses out freely, showing the prevailing laissez-faire attitude toward competition.

RATE HIKES: Consumers were outraged when deregulation caused electricity costs to skyrocket in Baltimore in 2006 [left] and in Illinois in 2007 [right].
PHOTOS: LEFT, CHRIS GARDNER/AP PHOTO; RIGHT: SETH PERLMAN/AP PHOTO

Also, politicians wanted to see the cost of electricity drop. (A kilowatt-hour in the late 1800s cost about US $5.00 in today's dollars; now it averages just 12 cents.)

It didn't take long, though, before Samuel Insull, a former Edison employee who became a utility entrepreneur in the Midwest, realized that the technology George Westinghouse was advocating—large steam or hydroelectric turbines linked to long-distance AC transmission lines—could provide electricity at lower cost. Using such equipment, his company soon drove its competitors out of business. Other big utilities followed Insull's lead and came to monopolize the electricity markets in New York, New Jersey, and the Southeast. But the rise of these companies was ultimately a bane to consumers, who had to pay exorbitant prices after the competition had been quashed.

Angered by the steep rates, consumers formed electricity cooperatives and municipal utilities. That in turn led Insull and his counterparts to plead with state officials for protection from this "ruinous" competition. Politicians complied, passing laws that granted the large electric power companies exclusive franchises in their areas in exchange for regulation of their prices and profits. The municipal utilities and electricity cooperatives continued to operate but in most cases never grew as large as the regulated for-profit (investor-owned) utilities.

This basic structure remained in place until the oil shocks of the 1970s. Real electricity prices rose by almost 50 percent during that troubled decade, despite having fallen virtually every year since the opening of Edison's Pearl Street station. One culprit was the widespread use of imported oil. The United States then generated almost 20 percent of its electricity using fuel oil; today that figure is less than 1 percent. And many utilities had made some poor investments—primarily in nuclear power—which their customers had to pay for.

The 1970s also exposed problems in how the electric power industry was regulated. Power grids were growing in complexity as different utilities began interconnecting, and many regulators—particularly those whose appointments were political favors—didn't understand the technical implications of their decisions. The combination of rising prices and obvious mismanagement led many large industrial consumers of electricity to push for deregulation.

The Public Utility Regulatory Policies Act of 1978 was the first shot fired in the ensuing battle. The new federal law allowed nonutility companies to generate electricity from "alternative" fuel sources (mostly natural gas), and it required utilities to sign long-term supply contracts with these new generating companies. The Energy Policy Act of 1992 expanded the pool of players in the wholesale electricity market by allowing financial institutions—Morgan Stanley being the first—to buy and sell bulk electric power. Yet neither act was effective in curbing electricity prices.

Two states, California and Pennsylvania, then decided to take more drastic measures. They established centralized spot markets for electricity and allowed individual customers to choose their electricity suppliers. While Pennsylvania's experiment has largely run smoothly, California's experience was quite different. After two years of reasonably stable operation, wholesale prices exploded in 2000, from a few cents per kilowatt-hour to more than a dollar per kilowatt-hour. One reason for those astronomical prices was that power-trading companies like Enron Corp. had figured out how to game the system. With retail prices capped by law at 6.7 cents per kilowatt-hour, two of the state's three investor-owned utilities, Pacific Gas & Electric and Southern California Edison, ran out of money to pay for electricity. That triggered a second power crisis the following year, which forced the state to buy electricity from producers. The long-term contracts signed during that period of panic buying saddled California taxpayers with a debt of some $40 billion.

For Californians, at least, deregulation had lost its gloss. This turned out to be temporary: The state recently reintroduced centralized wholesale markets modeled after Pennsylvania's. But has deregulation on the whole made things better or worse? Dozens of studies have attempted to answer that question. But you can't simply compare states that have aggressively deregulated with ones that haven't. That would ignore the fact that some states have built-in advantages that keep prices low: proximity to natural resources, a large base of generation capacity, and so forth. It also ignores what utilities and regulators would have done if deregulation had never happened.

To answer the question properly, you'd need to figure out what things would have been like in the absence of deregulation. And that's well-nigh impossible. Of the various studies that have attempted to assess the impacts of deregulation, most have come from groups with a stake in the outcome of the regulatory reform process. So they tend to be either strongly for deregulation or strongly against it. In reality, deregulation has had both good and bad effects.

Consider a simple variable like the price of electricity. That competition will lead to lower prices is about as close to a universal truth as economics gets. But electricity seems to be an exception.

Here's why: Under regulation, each generating plant is paid for its electricity based on its average cost plus some prescribed rate of return. In a competitive market, supply and demand set the price. That means that the last plant coming online to handle the load determines the wholesale price of electricity. All generators in the system are then paid that same amount for each kilowatt-hour they inject into the grid.

That might seem only fair, but you have to remember that not all electricity generators are created equal. In most places, coal and nuclear plants, which can't be ramped up and down easily, produce the roughly constant baseload power feeding the grid. If more is needed, natural gas turbines then kick in. So in deregulated markets, the price of gas, which has historically been higher than that of coal or nuclear fuel, ends up controlling the wholesale price of electricity—allowing the owners of nuclear plants and efficient coal plants to earn much higher profits than they did under regulation. That's why electricity prices in many places rose so sharply when natural gas prices skyrocketed at the turn of the millennium.

Other strange dynamics also come into play. For example, state political leaders realize that escalating or erratic electricity prices are bad for economic development (and their own chances of reelection). So they've fought hard to keep them low and stable by impos-

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ing rate caps and freezes. But many of these same states also compelled their electric utilities to divest themselves of generating capacity in an attempt to spur competition. And when electricity demand is high and the utilities don't have enough of their own generating capacity, they're forced to buy more on the spot market, where prices are volatile. The results have not been pretty. In 2000, one of California's two largest utilities went bankrupt, and the other nearly did. And when regulators in Maryland finally allowed retail electricity rates in Baltimore to float with wholesale electricity prices, the local utility immediately announced a rate increase of 72 percent, leading to consumer outrage and eventually to the summary firing of the entire public utility commission.

Clearly, deregulation hasn't been at all successful in bringing prices down. But has it made the companies that provide electricity more efficient? Very probably. Their labor costs have fallen, mostly through reductions in staff, while the reliability of their power plants has improved. The champions in this regard are the nuclear power stations, whose uptimes have risen from around 65 percent in the 1980s to over 90 percent today. This shouldn't be a surprise. Because the construction costs of most of these plants have been paid off and because nuclear generators have very low operating expenses, the plants have become extraordinarily profitable. So their owners strive to have them online as much as possible, investing as needed to keep them well maintained.

Maintaining some other parts of the grid infrastructure has, however, proved to be more of a struggle. In the old days, investments in transmission lines and generating stations were determined by consensus between each utility and its regulator. Deregulation's architects envisioned a different scenario—that entrepreneurial firms would automatically make the needed investments in hopes of profiting from them. That didn't exactly happen. One thing deregulation definitely did do, though, was to change the mix of fuels in the U.S. generation fleet, shifting it away from coal and nuclear power toward natural gas. That's because gas units are quick to build, and many are flexible enough to operate only when prices are high enough to warrant throwing their switches on. It helps, too, that natural gas is a cleaner fuel than coal and less controversial than nuclear power, which helps with public approval. Also, because companies generating electricity in a free market need to demonstrate a return on investment within 5 to 10 years, building big nuclear and coal plants, which usually take over a decade to complete, just isn't an option. So more and more of the grid's power comes from gas turbines, despite the high fuel costs.

The changing investment environment has also inflated the cost of building new infrastructure. The reason is obvious once you think about it. Regulated utilities can spread the burden of investment among all their customers, and the government guarantees that these companies can charge enough to recover their initial outlay and make a decent profit on it. So there's little financial risk in building a new plant or transmission line, allowing the companies to attract low-priced capital. Not so with unregulated utilities, whose fortunes depend on an uncertain market. The greater risk they face means they must offer higher returns to attract investors, and these increased financing costs make capital projects more expensive.

Depending on market-based investment in transmission lines has proved especially problematic. Deregulation's proponents believed that for-profit companies would recover the money they invested in transmission lines through "congestion pricing"—charging more when demand for these lines is high. Instead, lucrative congestion revenues have only given the owners of existing transmission lines an incentive *not* to build more capacity. And the general aversion people have to high-tension cables nearby—the "not in my backyard" effect—has made it almost impossible to construct new lines.

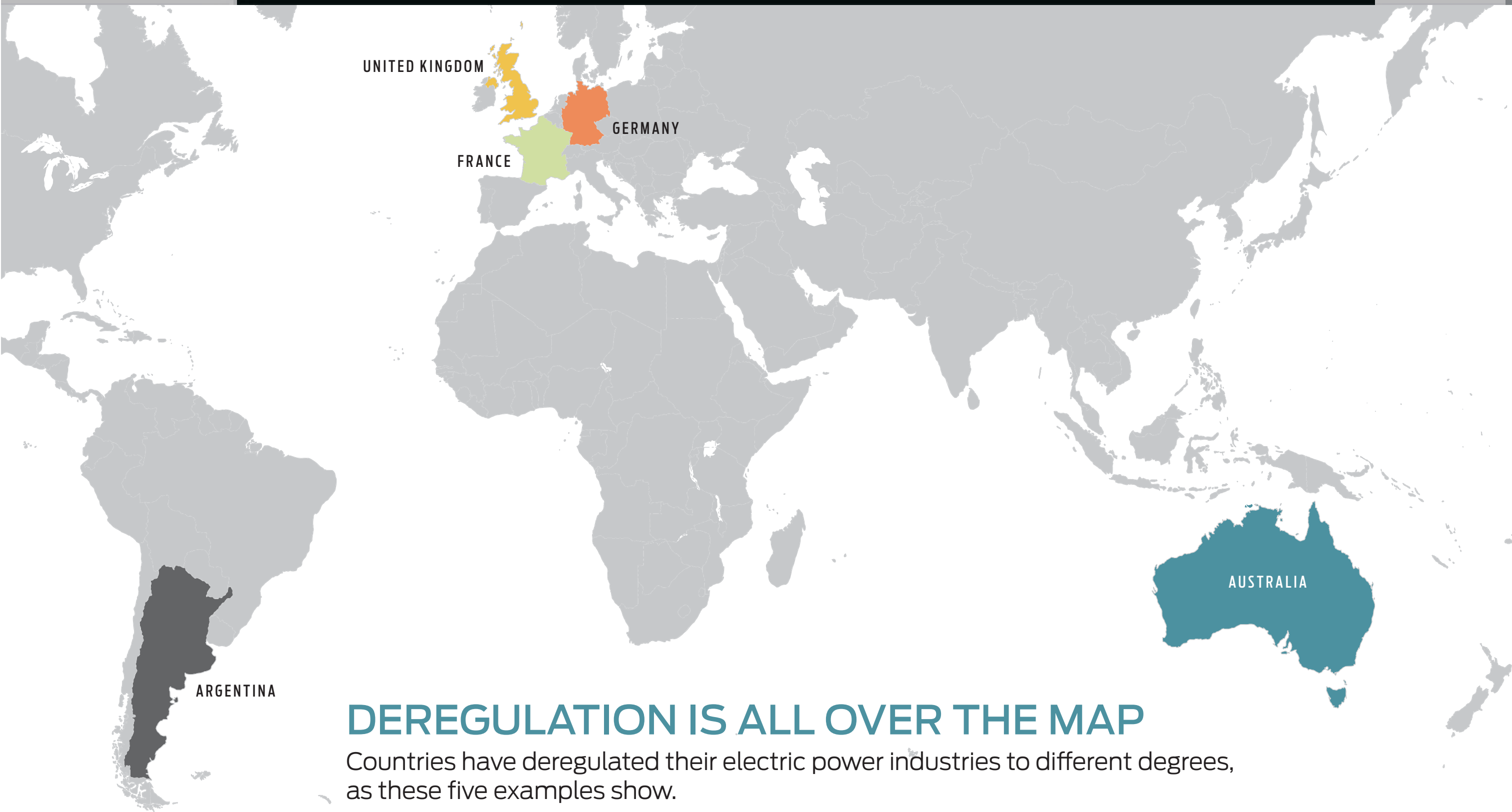
No great wonder, then, that investment in transmission lines and equipment has mostly been falling since the 1970s. Many people paid little notice to that fact, but the Northeast blackout of 2003 was a wake-up call. It began on a hot August afternoon with several seemingly trivial outages of transmission lines in Ohio, but by nighttime a series of cascading failures grew to plunge more than 50 million people in the Midwest, the Northeast, and Ontario into darkness. This episode convinced even skeptics that investment in the nation's electricity grid was lagging.

GIVEN DEREGULATION'S checkered record, you have to wonder how well competitive electricity markets will handle upcoming challenges. In particular, how will they reconcile the need for reliable, low-cost power with the environmental costs of producing it?

One much discussed way to use markets to benefit the environment is to put a price on emissions of carbon dioxide and other greenhouse gases. Many countries have already done this. But unless the price is set a lot higher than in Europe, U.S. utilities and generating companies aren't going to be abandoning their carbon-spewing coal plants anytime soon—they're just too profitable. Putting a dollar value on greenhouse gases might encourage some generators to invest in less carbon-intensive power sources where they can, but only if proper laws and regulations are in place to lower the risk. And that won't happen overnight.

In the meantime, 32 of the 50 U.S. states are trying to boost the use of renewables by mandating "renewable portfolio standards." These standards force utilities to buy considerable quantities of wind and solar power but also give them the freedom to shop for the least expensive sources. Also, the U.S. Department of Energy wants 20 percent of the nation's electricity to come from wind power by 2030. Government bodies are taking these actions because consumer demand alone hasn't sparked much renewable generation. That's not surprising. The wind and sun are notoriously fickle, which forces system operators to maintain plants that can fill in when necessary. Those backup generators are expensive, as are the transmission lines needed to link most renewable resources, which are located in sparsely populated areas, to the people using electricity. So the cost of generating "green" electricity is generally higher than the price it can command.

Renewable portfolio standards create a not-so-free market (but a market nevertheless) for wind and solar power while also pressuring these producers to keep their prices down. Policymakers in both regulated and deregulated states are also hoping to harness other market-based approaches to reducing electricity consumption. Using less electricity not only helps the environment, it can be just as effective as increasing supply in maintaining the reliability of the grid. And it's less expensive to boot.



DEREGULATION IS ALL OVER THE MAP

Countries have deregulated their electric power industries to different degrees, as these five examples show.

ARGENTINA

Privatization of electricity generation in Argentina began in 1992, followed the next year by privatization of that nation's six transmission companies. Argentine law did not allow any of the resultant for-profit power companies to control more than 10 percent of the country's generation capacity, ensuring considerable competition among them.

UNITED KINGDOM

Electricity restructuring in the UK began under Margaret Thatcher, with the Electricity Act of 1983, which gave independent power producers access to the national grid. Government-owned generators were then fully privatized in the 1990s.

FRANCE

France began a very modest program of reform in 2001, but for the most part electricity supply remains completely dominated by the state electricity company, Électricité de France.

GERMANY

In response to a 1996 European directive, Germany abolished its law exempting electricity from competition in 1998. But most of that country's electricity still comes from just a few vertically integrated power companies, with comparatively little electricity trading on open exchanges.

AUSTRALIA

The Australian state of Victoria privatized its electricity sector in 1994. Some other Australian states soon followed suit. And Australia established a national wholesale electricity market in December 1998.

The most straightforward way to discourage electricity use is, of course, to charge a lot for it. But U.S. consumers, and the lawmakers who represent them, are never too keen on that. Another strategy now being explored—one that's less of a political hot potato—is to have utility operators offer their customers compensation for reducing their demand for electricity during times of peak use. A reduction in demand allows utilities to avoid having to buy so much electricity when wholesale costs are at their highest. This approach provides an enticement to consumers to react to market signals, even if they are not yet ready to face them squarely in the form of higher prices.

Another advance that probably wouldn't have come about without deregulation is the emergence of small-scale, distributed generation, particularly from renewable sources such as rooftop solar panels. What's happening in many places is that customers are producing some electricity on their own while still attached to the grid. So they can offset some of the electricity they would otherwise consume, perhaps even spinning their meters backward at times. Although this practice competes with the electricity that the utility sells, more and more utilities are nevertheless allowing it to a greater or lesser degree.

IN HINDSIGHT, the electricity crisis in California and the myriad problems with deregulation in other parts of the country could have been anticipated. Given the complex market rules, concentrated supply, and largely inelastic demand, it's really no wonder that Enron, other energy-trading companies, and the electricity suppliers themselves found clever ways to manipulate markets.

Would U.S. consumers have been better off if the industry had remained strictly regulated? It all depends. If your goal is low electricity rates, maybe the answer is yes—but don't forget that bad regulatory decisions helped drive up electricity prices in the first place. If, however, you want the ability to feed power from your rooftop solar panels into the grid, the answer is probably no.

The real question facing the United States now is whether it can maintain reliable electricity grids without building lots of new transmission lines and big power plants. The only realistic alternative to such massive construction projects is for the generation of electricity to become more widely distributed, coupled with substantial efforts in energy efficiency. Electricity markets will surely have to become more expansive and open to accommodate that inevitable evolution. And they will also require new technical standards and, yes, some new forms of regulation. ❑

JOIN THE DISCUSSION at http://spectrum.ieee.org/dereg1210

3-D *without* FOUR EYES

3-D displays are trying to shed their spectacles

BY MARK HARRIS

Beautifully animated figures seem to be leaping out of the game player I'm holding. Planes and cars are swooping toward me so convincingly that I'm actually flinching. The graphics are detailed; the colors are natural. I've never had a better 3-D experience, and here's the best part: This handheld, multidimensional marvel, a prototype from 3M, doesn't require me to wear those clunky, chunky 3-D eyeglasses.

New glasses-free 3-D devices are about to hit the market, and their backers are hoping they'll make 3-D spectacles as obsolete as Smell-O-Vision. These gadgets, described as "autostereo" to distinguish them from the kind requiring eyewear, will include not only game consoles like the one I've been playing with but also cameras, cellphones, and tablet computers. Among the first will be autostereo 3-D TVs, just now hitting stores in Japan, and Nintendo's 3DS handheld games console, due for release worldwide early next year.

To perceive three dimensions, a person's eyes must see different, slightly unaligned images. In the real world, the spacing between the eyes makes that happen naturally. On a video screen, it's not so simple; one display somehow has to present a different and separate view to each eye. Some systems handle this challenge by interspersing the left and right views; they're called multiplexed. Others, called sequential, alternate left and right views. Whatever the approach, the displays then use optical or technological tricks to direct the correct view to the correct eye.

For example, the bulkiest glasses used with currently available 3-D TVs are active-shutter glasses. They contain a set of miniature LCD panels that synchronize with the large LCD screen in the TV. When the main screen is showing an image destined for your right eye, a liquid-crystal shutter in the left lens of the glasses makes that lens opaque, and vice versa. This sequential system switches between images meant for each eye dozens of times a second, creating a smooth 3-D effect.

It works well. In theory, at least. According to a survey of 1400 Americans by the market research firm Interpret, a quarter of gamers got headaches from 3-D, a fifth complained of eyestrain, and one in six said that they felt disoriented or dizzy after playing. In a similar survey of 2000 Americans by the market research firm NPD Group, over half said that having to wear glasses would discourage them from upgrading to 3-D altogether.

And the glasses aren't cheap. High-tech 3-D specs cost US $100 or more, and a pair bought from, say, Sony typically won't work with a Panasonic or LG Electronics TV.

PHOTO: DAN SAELINGER; PROP STYLING: LAURIE RAAB/HALLEY RESOURCES


XPAND
SONY

The first to swear off glasses was Nintendo. At the Electronic Entertainment Expo games show in June, Nintendo announced the 3DS console, an autostereo handheld gaming device. It will launch early in 2011 with two built-in screens: one touch sensitive but limited to 2-D, the other a 3.5-inch display with the 3-D effect.

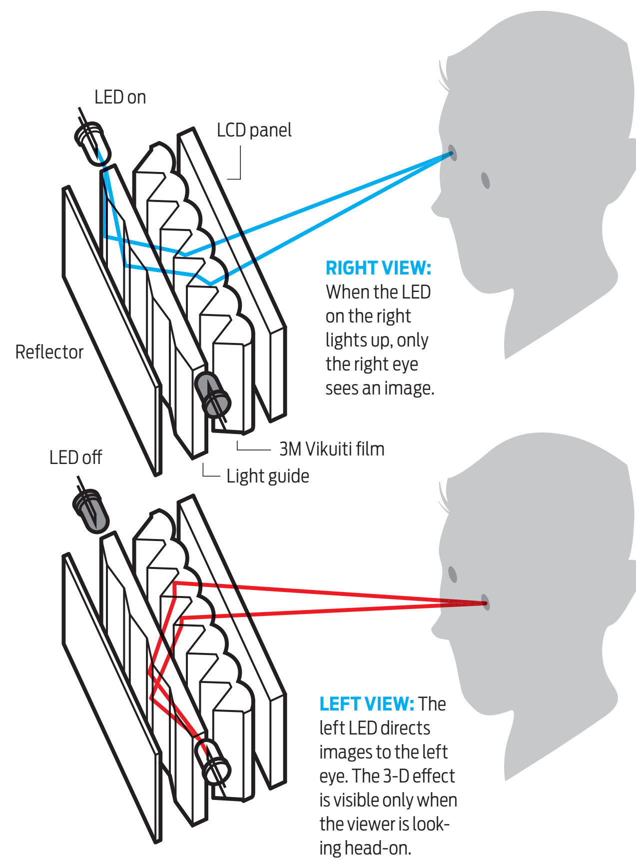
Nintendo last dabbled in 3-D 20 years ago, with *Famicon Grand Prix II: 3D Hot Rally*, a disc-based racing game using active-shutter glasses. Even in gadget-mad Japan, the heavy, flickery, first-generation goggles proved unpopular. "Since then, we've tried 3-D many times without announcing it, searching for a way to make it a product for the mass market," says Satoru Iwata, president and CEO of Nintendo. "With the 3DS, 3-D effects finally give a much better sense of height, depth, and width. You get a much better ability to navigate and judge distance."

The Nintendo 3DS's autostereo screen, made by Sharp, uses a multiplexed "parallax barrier" technology. This method lays a second layer of liquid crystals next to a traditional LCD and its backlight. This extra layer creates thin vertical strips that block some of the light and direct the remaining light alternately to the left and right eyes, creating a 3-D effect for a single viewer at a set distance, usually around 30 centimeters. More on that later.

Parallax barrier technology does have a few problems. Because the multiple layers of crystals prevent some light from reaching the user, getting to an acceptable level of brightness means cranking up the backlight, sucking up power and quickly draining batteries in portable devices. And because each eye sees only half a screen's total pixels, the technique cuts the effective resolution in half. So manufacturers must choose between a display of standard resolution and brightness—and suffer dull, low-resolution 3-D graphics—or upgrade to a brighter, higher resolution screen that's also pricey and power hungry.

Nintendo split the difference with its new console, bumping the brightness up but keeping the resolution relatively low. The 3DS has an 800- by 240-pixel screen that delivers 400- by 240-pixel views to each eye. While this is a step up from the 256-by-192 screen of its predecessor, the Nintendo DSi, it is just one-sixth the resolution found on the similarly sized Apple iPhone 4. Put simply, you wouldn't want to watch a movie—or even view a photo slideshow—on the 3DS.

Parallax barrier displays also have sensitive geometries that deliver optimum 3-D effects only at a particular eye-separation distance—as close as possible to the statistical average of 65 millimeters. These displays are also tuned for a specific distance from screen to eye, with the 3-D effect fading if that distance is off by as little as 5 centimeters. This distance sensitivity is less of an issue for handheld devices than freestanding displays, explains Michael Bove, director of the consumer electronics laboratory at MIT. "We know how long people's arms are, so the viewing distance is bounded," he says. "And people will naturally move the thing around until it looks right." Still, says Nick Holliman, senior lecturer in engineering and computing sciences at Durham University, in England, "If you tune an image for an adult, it may not work so well for kids."



3M Vikuiti

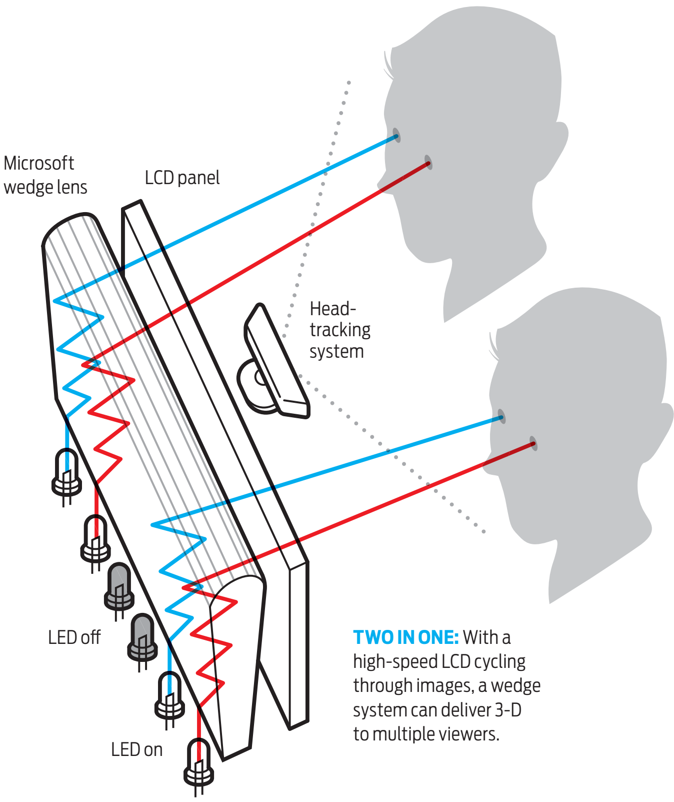
In 3M's Vikuiti display, LEDs on opposite ends of a plastic film alternate on and off for a total of 120 flashes a second, in synchrony with the changing images on an LCD panel. Microscopic bumps on the film direct the light to the appropriate eye to create the 3-D effect.

JAMES PROVOST

Nintendo recognized these issues, says Shigeru Miyamoto, designer of the legendary *Mario* and *Donkey Kong* games and now general manager of Nintendo's R&D division. "Everyone sees 3-D images differently," he notes. "I wanted everyone to be able to instinctively adjust settings for themselves, as easily as changing volume." So the 3DS comes with a slider that changes the differences between the left and right images to increase or reduce the 3-D effect, or remove it altogether.

That slider doesn't solve all of parallax barrier's problems. If you move from a head-on viewing position, your left eye will see the image destined for your right—Pinocchio's nose, for example, will suddenly seem to grow inward. Move a little farther and the 3-D effect might flip-flop. What's more, light leaking through the LCD barrier layer could cause cross talk, a mixing of left and right views that creates ghosting—the blur that's one of the biggest complaints about autostereo gizmos. Together, these effects can cause that dreaded 3-D nausea.

"Your brain is receiving ambiguous messages," says Bove.



TWO IN ONE: With a high-speed LCD cycling through images, a wedge system can deliver 3-D to multiple viewers.

MICROSOFT *Wedge*

The wedge-shaped lens in Microsoft's autostereo display takes the light from multiple LEDs and turns it into a solid beam. Illuminating different LEDs steers the beam alternately to the left and right eyes; a head-tracking system finds the viewer to make sure the beams go to the right place.

"It might interpret them as two objects at two different depths, or as mostly a 2-D screen with something funny going on. Often, it just gives up, and you get a headache or a stomachache."

Engineers are trying to fix these problems. In Sharp's latest 3-D displays, the transistors that control each pixel use the company's proprietary continuous-grain silicon technology; these transistors are thinner than ones fabricated from traditional polycrystalline silicon and they allow more light to pass through, increasing the brightness of the layered screens.

Researchers have also experimented with autostereo displays that generate multiple sets of 3-D images, either to accommodate several viewers simultaneously or to reduce the flip-flopping effect when your head moves relative to the screen. There's a trade-off, of course: Each added set of 3-D images divides the screen's effective resolution and requires more processing power. According to Holliman, "If you use multiview, you get too low a resolution per view for a game to be acceptable or possibly even playable."

THERE ARE emerging alternatives to parallax barrier screens. Some are new; others are reinventions of technology that has been around for a long time.

You've certainly seen lenticular postcards, first popularized in the 1950s. They generate a 3-D image or a changing 2-D scene by overlaying a rippled sheet of transparent plastic on two interlaced images—a classic multiplexed 3-D system. The rippled sheet acts like a set of lenses, throwing an image of one series of image strips to your left eye and the other series to your right. Lenticular LCD screens work in a similar way with moving images—this is the technology that Toshiba uses in its recently announced autostereo TVs, which it expects to have in stores in Japan by the end of the year. However, lenticular 3-D effects reduce a display's resolution and are visible only from specific, narrow viewing angles. That might make it pretty tough to, say, watch a 3-D football game with more than one friend. "People want to put chairs where they're comfortable, not necessarily where the right view zones are," notes MIT's Bove.

More innovative are 3-D screens based on so-called wedge lens technology, pioneered by Adrian Travis when he was at the University of Cambridge, in England. (Travis moved to Microsoft's Applied Sciences Group in 2007, bringing his technology with him.) "The wedge is better than parallax barrier and lenticular because it doesn't throw away half the resolution," Travis says.

If that makes the wedge sound like a sequential 3-D display, you're right—but it's a very special one. Instead of throwing light in all directions like a TV screen, the wedge lens shines focused beams in specific directions. If you know where the viewers are sitting, and alternate those beams precisely to their left and right eyes, you'd have an extremely efficient 3-D display, because you wouldn't be wasting light on empty chairs. "We use maybe half the power—and in principle much, much less than half—of a normal 2-D display," says Travis.

The wedge is basically a flat lens, twice as thick at one end as at the other. It covers the entire viewing screen, which is an ordinary LED-backlit LCD. The thick end is curved and faceted so that it lines up the beams from the LED backlights, creating a solid beam in just one direction. Activating different LEDs in the backlight creates beams that project in different directions. A prototype using a fast (240-hertz) LCD panel produces smooth autostereo 3-D, with little cross talk and no flip-flopping.

The toughest trick for the wedge is figuring out just where to point those beams. But it may get some help with that from another development at Microsoft. "Head tracking using Microsoft's Kinect technology is the direction we're traveling in," says Travis, referring to a new $150 accessory for Microsoft's Xbox 360 console that uses near-infrared cameras and sophisticated software to follow gamers' motions.

Although Travis expects some form of the wedge to feature in consumer gadgets within two years, he admits, "Head-tracking 3-D is further out. However, I think there's a good chance we will ultimately be able to get it to fit into a phone."

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But Microsoft's struggles are good news for 3M. Not only has the St. Paul, Minn.–based company managed to get sequential autostereo working well, it's gotten it small enough to fit in the device I'm holding right now. 3M's senior technical manager, Bill Bryan, doesn't mince his words: "There hasn't been a bigger improvement to the viewing experience since the introduction of color screens." Of course, he *would* say that, wouldn't he? But there's no denying that 3M's new Vikuiti 3-D technology is something special.

I viewed the Vikuiti 3-D effect on both 3-inch and 9-inch screens, and I found it to be startlingly bright, crisp, and vivid when seen head-on. If you do move to one side, the images fade gracefully into 2-D. At a trade show last May in Seattle, 3M's LCD business director, Erik Jostes, showed off a 9-inch model. The company was running a show reel of animated gaming characters and also some smooth, full-resolution video.

Basically, this is the 3-D display we've been promised in science fiction films for the last 50 years. And an early version of it, which suffers from slightly more cross talk than the 3M models, is available today, in Fujifilm's W1 3-D digital camera.

To understand the 3M system, start with the fact that most LCD screens are transmissive; they have a backlight that shines through the liquid crystal panel to form an image. In handheld devices, the backlight LEDs are located at the display's edge to save space. A single row of LEDs constantly shines into a plastic light guide that, as its name suggests, directs and disperses light in the correct direction—up and out of the display. For years, 3M has been creating optical films that help move this light evenly from the sides into, across, and out of the liquid crystal panels, increasing their effective brightness. The company has now come up with the Vikuiti optical film, which can direct images to one eye or the other.

HANDS ON: Nintendo lets gamers get their hands on autostereo 3-D at the official launch of its 3DS handheld system this past September, in Chiba, Japan. The device won't hit store shelves there until February.
PHOTO: YOSHIKAZU TSUNO/AFP/GETTY IMAGES

This autostereo 3-D system has a light guide with a column of LEDs mounted on either side of the screen; the columns flash alternately 120 times a second. Each burst of light travels through the light guide as usual, then up into the Vikuiti optical film. Inside the film are microscopic bumps—finely engineered features that act as tiny lenses. When light from the left-side LEDs shines on them, they direct light to the user's left eye, and when light shines on them from the right-side LEDs, the image is directed to the right eye. Flashes of left and right light are easy enough to produce, but for the screen to form an image, the LCD panel above the film must be perfectly synchronized with those flashes, showing only the left image when the left-side LEDs are on and the right image for the right-side LEDs.

The Vikuiti screen has just one 3-D sweet spot, straight out from the screen. At this point it's definitely intended for personal viewing, not Super Bowl parties.

In order to direct light reliably to each eye at the correct viewing position, 3M needs to manufacture the microscopic lenses—the bumps—with extreme precision. The film is just 150 micrometers thick (around twice as wide as a human hair), with the lenses measuring a mere 50 to 70 µm. Perfecting this film took 3M over three years, and developing the techniques necessary to produce the film in commercial quantities took another year.

With no optical barriers or screen-mounted lenses to reduce the brightness or resolution, the 3M film creates autostereo 3-D video that looks just as sharp as traditional 2-D images. But 3M's Vikuiti film shares some of the problems of other 3-D systems. Like the Nintendo 3DS's parallax barrier system, the Vikuiti 3-D effect works in only one direction, typically landscape. Rotate the screen, as cellphone users are in the habit of doing, and the 3-D effect simply disappears. The 3-D effect is also sensitive to interpupillary distance.

Finally, the effect requires a high-speed (120-Hz) LCD panel to deliver those sequential frames without jerkiness. These are more expensive than standard 60-Hz LCD panels. "The panels have to catch up. The graphics chips have to catch up. And because you're driving the LCDs harder, the power consumption will be higher in 3-D mode, too," admits 3M's Jostes. "If you want 3-D, you essentially have to double the processing speed." In short, it needs the kind of high-powered smartphones and tablets that are only just starting to arrive in the marketplace. These are unlikely to add pricey 3-D features until manufacturers perceive a real consumer demand, although Chinese company Rockchip has demonstrated a prototype autostereo Android tablet.

"With the first panels, there will be a slight cost premium," says Bryan. "There has been a chicken-and-egg situation around 3-D—how can you make a device when there's no content? And why make content if there's no device to view it on?"

Today, however, the Nintendo 3DS and its high-profile games are hatching chickens and laying eggs simultaneously; the industry could finally be gearing up for a handheld 3-D revolution. Unlike 3-D movies that require expensive multicamera setups, 3-D games can be developed at a premium of just 10 to 15 percent over their 2-D equivalents, according to game analysts at Futuresource Consulting. "Now that Nintendo has come out and said we're going to do 3-D, other companies will think about moving towards it as well," says Jostes. "Our expectation is that demand for 3-D is going to be driven by gaming."

Steve Vrablik, a director of business development at Toshiba America Electronic Components, is thinking even bigger. His company supplies LCDs to smartphone manufacturers and showed the 3M Vikuiti film in several devices at a recent trade show. "Last year, people looked at the prototypes and walked away," he says. "This year, they're saying, let's talk."

Glasses-free (and headache-free) 3-D could be the new must-have upgrade for cellphones—like GPS location, digital photography, and music playing before it. Industry research association DisplaySearch predicts that by 2018, mobile devices will have leapfrogged televisions to become the most popular 3-D gadgets, selling over 70 million units a year. MIT's Bove won't predict which autostereo technology will triumph, but he is convinced that the most successful devices will all be handheld.

"There are lots of things you can do on a screen the size of a business card that you just can't afford to do for a larger display," he says. "Whatever your magic component is in this domain, you don't need a lot of it."

And without those headache-inducing spectacles to contend with, you shouldn't need a lot of Tylenol, either. ❑

TELL US WHAT YOU THINK at http://spectrum.ieee.org/3dvideo1210

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2) a complete CV,
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The Faculty comprises five departments: The Department of Computing, Department of Electrical Engineering, Department of Electronic and Information Engineering, Department of Industrial and Systems Engineering and Department of Mechanical Engineering and is also home to a number of research centres in Advanced Manufacturing Technology, Biometrics, Combustion & Pollution Control, Fluid-structure Interactions, Integrated Product Development, Consortium for Sound and Vibration, Knowledge Management, Photonics and Power Electronics. In keeping with the University's mission of "Academic Excellence in a Professional Context", the Faculty endeavours to meet engineering trends by offering high-quality postgraduate (including Engineering Doctorate), undergraduate and higher diploma programmes and undertaking cutting-edge research. In the past five years, academic staff of the Faculty have published over 2,860 journal papers, made some 2,200 international conference paper presentations and solicited external research grants amounting to more than HK$237 million. Please visit the website at http://www.polyu.edu.hk/feng/ for more information about the Faculty.

The University is now inviting applications and nominations for the post of Dean of Faculty of Engineering. The successful candidate will be appointed as Chair Professor/Professor, commensurate with his/her qualifications and experience, and hold a concurrent deanship appointment.

The position calls for a visionary leader and distinguished scholar with responsibilities of ensuring the smooth and successful operation and sustainable development of the Faculty and its constituent departments. Reporting directly to the Deputy President and Provost, the appointee will be required to provide effective leadership in the development of long-term strategies and plans of the Faculty as well as support to overseeing departments for the accomplishment of strategic objectives. Other responsibilities include inspiring excellence in teaching, research and services; fostering strong academic partnerships and collaborations with external organizations; ensuring optimal deployment of human, financial and other resources in the Faculty; and implementing an effective mechanism to acquire donations and other forms of sponsorship to support the University's pursuits and long-term development.

Applicants should have outstanding academic qualifications at doctoral level in Engineering related disciplines, evidence of eminent scholarship and substantial relevant experience in a senior academic position. The ability to promote collaboration across faculties and departments, effective communication, interpersonal and resources management skills, and excellent adaptability to changes and challenges are essential. Experience in fund-raising will be an additional advantage.

Further details about the post are available at http://www.polyu.edu.hk/hro/postspec/10101101.pdf.

Remuneration and Conditions of Service
Terms of appointment and remuneration package are negotiable and highly competitive.

Application
Applicants are invited to send detailed curriculum vitae with names and addresses of two referees to the **Human Resources Office, 13/F, Li Ka Shing Tower, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong [Fax: (852) 2764 3374; E-mail: hrscfeng@polyu.edu.hk], quoting position applied for and reference number. Recruitment will continue until the position is filled. Initial consideration of applications will commence in February 2011.** Candidature may be obtained by nomination. The University reserves the right not to fill this post or to make an appointment by invitation. General information about the University is available on the University's World Wide Web Homepage http://www.polyu.edu.hk or from the Human Resources Office [Tel: (852) 2766 5343]. Details of the University's Personal Information Collection Statement for recruitment can be found at http://www.polyu.edu.hk/hro/jobpics.htm.

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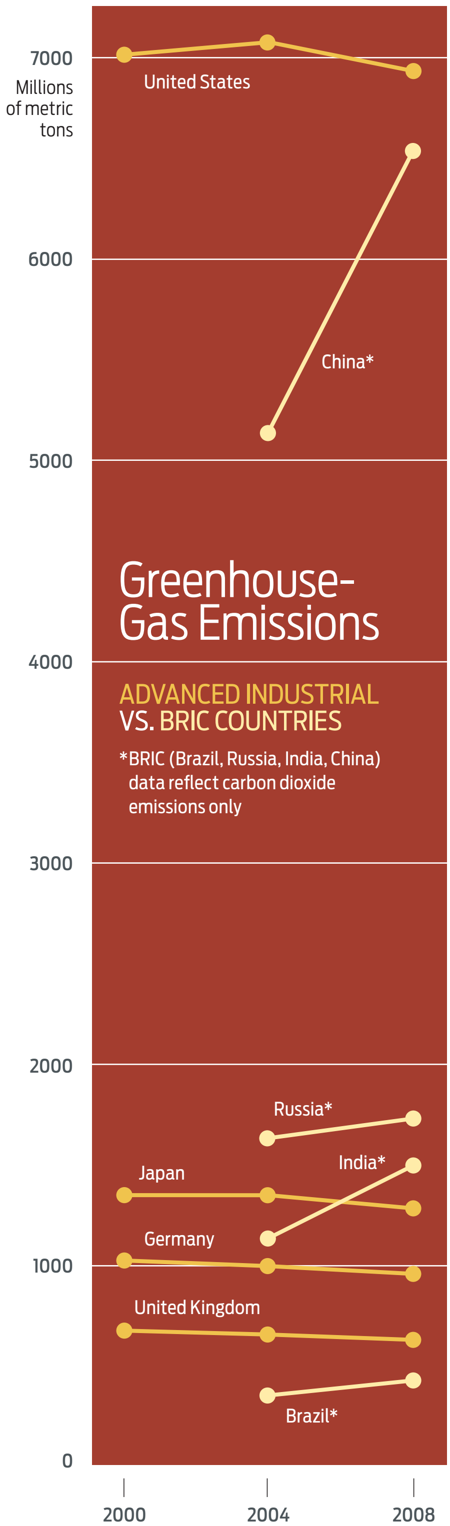
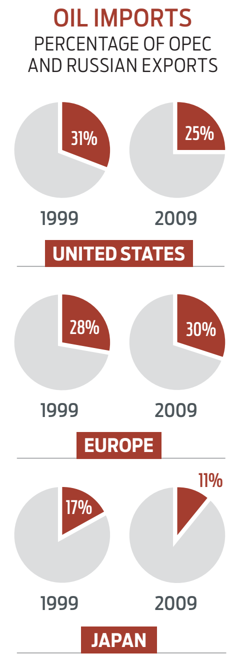
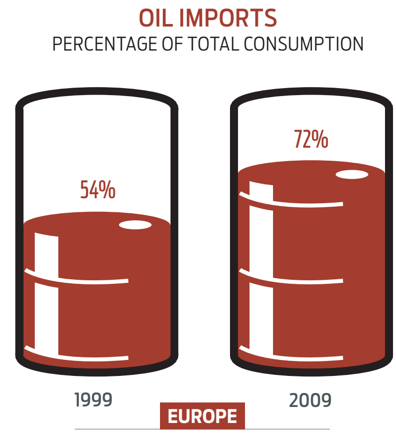
the data







Europe gets a rising share of its oil from OPEC and the Russian region. With Europe also getting more than a third of its natural gas from the Russian zone, it is now more dependent on unreliable exports than is the United States, whose position has improved slightly since 1999.

Energy & Climate: All Talk, No Action?

EVEN IF you regard energy independence as absurd and global warming a hoax, you can be sure that reducing fossil fuel imports and cutting greenhouse-gas emissions will long be twin guideposts to policy and investment decisions. So it seems sensible to take stock of how the advanced industrial countries have been doing. Here's what the latest available numbers show:

Japan's dependence on insecure OPEC and Russian-region oil has decreased, while Europe's dependence has increased even more markedly.

The countries most supportive of the Kyoto Protocol—Germany, Japan, and the United Kingdom—have gone a long way toward keeping their commitments. But the United States has not kept pace, and there has been a sharp rise in the emissions of the so-called BRIC (Brazil, Russia, India, and China) countries, especially China.

U.S. emissions decreased just 1.2 percent from 2000 to 2008, while Germany's and the United Kingdom's dropped 6.5 percent and Japan's 4.6 percent.

The 15 European countries that originally signed the Kyoto Protocol targets have cut their emissions by 3.5 percent since 2000, and the 27-member European Union of today by 2.4 percent.

—William Sweet

Sources

Greenhouse-gas emissions: United Nations Framework Convention on Climate Change, Greenhouse Gas Inventory Data, detailed by party

Total carbon dioxide emissions for BRIC countries: U.S. Energy Information Administration, International Energy Statistics

Oil imports: BP Statistical Review of World Energy, June 2010


Can piezoelectric nanogenerators make air travel safer?
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