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THE MAGAZINE OF TECHNOLOGY INSIDERS

04.08

TOP 10 TECH CARS

EVEN SUPERCARS CAN BE GREEN

A SPECIAL REPORT

TINY AND CLEAN MERCEDES-BENZ F700 ENGINE HAS THE POWER OF A BIG V6

AFTER 372 YEARS, HARVARD GETS SERIOUS ABOUT ENGINEERING

HOW THE U.S. DEPARTMENT OF DEFENSE COPES WITH OBSOLESCENCE

MEASURING SOLAR-CELL EFFICIENCY

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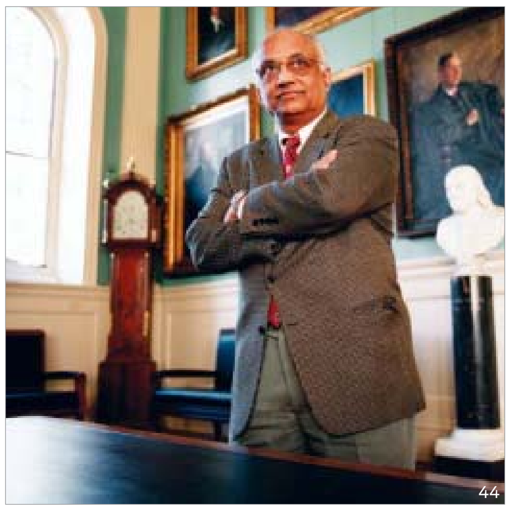
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THE JAGUAR XF [top] senses the driver's every movement; the ghosts of devices past linger in an aftermarket warehouse [left]; Venkatesh Narayanamurti has big plans for engineering at Harvard [right].

COVER: MERCEDES-BENZ

CLOCKWISE FROM TOP: JAGUAR; BRAD DeCECCO; BOB O'CONNOR

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volume 45 number 4 international

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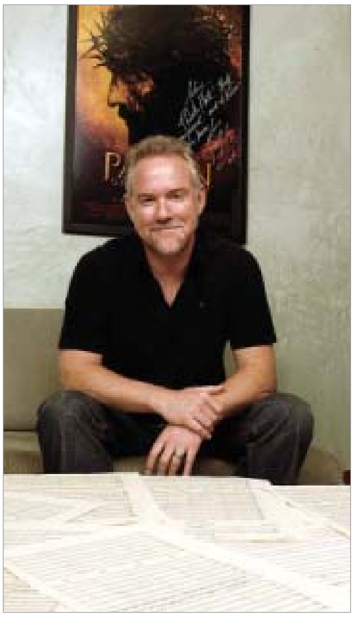

JOHN DEBNEY turns his talents from the big screen to the gaming screen.

PHOTOS: ABOVE: RUDY KOPPL (2); RIGHT: ANDREAS REH/ISTOCKPHOTO

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COMING IN APRIL TO SPECTRUM ONLINE

SWEET MUSIC FOR GAMERS' EARS

Last year, composer John Debney set film work aside to write the score for the hit video game *Lair*, because he believes composing for video games is the better gig these days. It's a surprising idea coming from someone who has won three Emmy Awards and in 2004 was nominated for an Academy Award for Best Original Score. He also says that the video-game community, more than Hollywood, "is where a lot of the more imaginative people reside right now." *Spectrum*'s Steven Cherry spoke to Debney before the 2008 Game Developers Conference.

ONLINE FEATURES:

ROBOTS TO THE RESCUE
Hurricane Katrina can teach makers of search-and-rescue robots new tricks.

CAR TALK
Listen to John Voelcker chat with *IEEE Spectrum*'s editor, Susan Hassler, about the coolest new cars.

GOOGLING WITH BRAINS
Image analysts use their own brain signals to find what they're looking for.

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IEEE.TV PROGRAMS ZERO IN ON THE ENVIRONMENT

IEEE's online television network has launched a series of four programs focused on environmental topics like e-cycling, green engineering, toxic electronics, and how to minimize the impact of electronics manufacturing.

NEW LOOK, NEW FEATURES FOR IEEE JOB SITE

The IEEE Job Site recently got a makeover, complete with career-related news, e-mail alerts about jobs that match your search criteria, and tools that let you quickly and easily create, customize, and upload résumés and cover letters.

YOUTUBE AND THE IEEE

Student members have been posting videos about the IEEE on YouTube. Read how a video produced by the student branch at Louisiana Tech University, in Ruston, inspired a recent IEEE-USA YouTube student video competition, and find out which school won.

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back story

A Gearhead's Motorhead

ONE AFTERNOON in November 2003, John Voelcker was driving the back roads near Woodstock, N.Y., when he got a call from a colleague from his days at *IEEE Spectrum* in the 1980s. It was Glenn Zorpette, now *Spectrum*'s executive editor, who wanted to know whether Voelcker would like to do a feature story called "Top 10 Tech Cars"—but Zorpette could hardly finish the question. "Are you kidding?" Voelcker shot back. "Of *course* I would!" And he's done it ever since.

This January he went to the North American International Auto Show, in Detroit, one of the global auto industry's most visible events. In three days packed with 37 scheduled media events, Voelcker interviewed engineers and executives; attended a blizzard of receptions, dinners, and social events; and eyeballed a lot of vehicles (the photo above shows him standing in front of Toyota's A-BAT hybrid concept truck). He boiled it all down as part of this year's story.

Voelcker—now *Spectrum*'s automotive editor—has attended technical conferences in Florida, California, and Washington, D.C., and auto shows in London, Los Angeles, and his hometown of New York City. He's driven a fuel-cell vehicle on a U.S. Marine Corps base in California and watched college engineering teams compete on General Motors' tracks in Michigan and Arizona.

The most memorable venue, he said, was the abandoned officer housing at a former Air Force Base in California's high desert. There Voelcker watched robotic vehicles navigate ghostly suburban streets amid dozens of identical Ford Taurus sedans piloted by professional stunt drivers, in the DARPA Urban Challenge.

What drives this self-admitted "motorhead," the son of an electrical engineering professor? "Between now and the end of my life, what we call an 'automobile' will change profoundly," he says. "I want to help explain those changes and get people thinking about what they mean." ❑

JOHN VOELCKER

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, the first Update page is in *IEEE Spectrum,* Vol. 45, no. 4 (INT), April 2008, p. 7, or in *IEEE Spectrum,* Vol. 45, no. 4 (NA), April 2008, p. 11.

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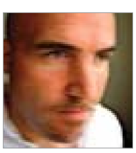
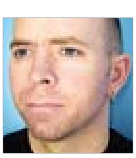
contributors

BRAD DeCECCO, originally from Massachusetts, shot the photos for "Engineering the Harvard Engineer" [p. 44]. "The clean rooms in the new Harvard engineering building were really awesome visually," he says. "The only bad moment was being stopped by campus police for driving the wrong way in Harvard Yard."

PETER FAIRLEY frequently writes about energy for *IEEE Spectrum*. In "Solar-Cell Squabble" [p. 32], he covers an ongoing controversy among organic photovoltaic researchers. After interviewing people on all sides, Fairley concluded that "discerning the real progress happening in solar power from the hype ain't easy."

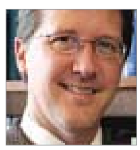


GREG MABLY, who illustrated "Solar-Cell Squabble" [p. 32], draws inspiration from such sources as nature, typography, mid-20th-century design, and psychedelia. His bold, whimsical designs have been used on wrapping paper, greeting cards, and posters. This is Mably's first feature assignment for *IEEE Spectrum*.



BOB O'CONNOR photographed towering shelves of mothballed electronic components at Rochester Electronics for "Trapped on Technology's Trailing Edge" [p. 38]. He shoots architecture and environments with an eye toward conveying a sense of scale. A self-professed neat freak, he enjoyed the cleanliness and organization of the warehouse.

PRACHI PATEL-PREDD writes about science, technology, and the environment. She's covered both the advantages and the risks of nanotechnology, so she was a perfect fit for reporting the slow-to-arrive breakthrough examined in "Carbon-Nanotube Wiring Gets Real" [p. 10]. Patel-Predd is also frequently heard on Spectrum Radio.



PETER SANDBORN is a University of Maryland professor of mechanical engineering. In "Trapped on Technology's Trailing Edge" [p. 38], he explores the dark side of Moore's Law, where technological change translates into nightmares, not opportunities. "Every time I have to buy more memory for my PC to run a new version of software, the impact of technology obsolescence hits home," Sandborn says.

PAUL WALLICH likes machines to do things his way, and if he can't build them himself, he'll make over a store-bought model. "It's what I've done for every computer I've owned since my first Kaypro," he says. Read about his latest such foray in "Hacking the Nokia N800" [p. 21].

CORINNA WU interviewed Don McMillan, an electrical engineer–turned–comedian, for Careers [p. 19]. McMillan is perhaps the only comic around who uses PowerPoint in his routine. For Tools & Toys last month, Wu wrote about the GigaPan, a robotic photographer that weaves successive shots into a single panoramic view.

CLOCKWISE FROM TOP LEFT: JR DELIA; JOEL PREDD; UNIVERSITY OF MARYLAND; JULIE ROBICHAUX; CORINNA WU; BOB O'CONNOR; GREG MABLY; RANDI SILBERMAN

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GM is betting on the series plug-in hybrid; Toyota is betting on the power-split plug-in hybrid. Tens of billions of dollars are at stake

spectral lines

GM'S 1997 all-electric EV1 [above] failed, but its successor, the plug-in hybrid Chevy Volt, boasts promising new technology.

PHOTO: CAR CULTURE/CORBIS

An Almost All-Electric Car?

REMEMBER GENERAL Motors' all-electric plug-in vehicle, the EV1? It went to market in 1997, mostly in California, became a Hollywood and media darling, and vanished without a trace six years later after a paltry 1000 e-cars were leased. Depending on your political persuasion and tolerance for conspiracy theories, the car-killing forces included fickle consumer interest, poor battery life, corporate greed, global oil agendas, and government ineptitude. *Who Killed the Electric Car?*, a 2006 documentary, cinematically indicted all of the above, and more, for terminating interest in electric-vehicle programs worldwide.

Well, despite all the post-EV1 talk that America's premier automaker had cynically jettisoned its electric and alternative-fuel dreams to pursue gas-guzzling SUV cash cows, GM seems never to have abandoned the e-car game. This time the automaker's back with some economical gas/electric hybrids and fuel-cell vehicles, including a fuel-cell SUV. But the big news is GM's snappy new hybrid plug-in technology, used in the Chevrolet Volt concept car, which some are touting as the Toyota killer.

Responding to heightened global concerns about greenhouse-gas emissions—and a new Washington mandate requiring cars to average 35 miles per gallon (6.7 liters per 100 kilometers) by 2020—both GM, the No. 1 automaker, and Toyota, the heir apparent, have said they hope to have different but affordable, efficient plug-in hybrid vehicles (or PHEVs) on the lot by 2011 [see my article "Top 10 Tech Cars" in this issue to learn more about what's happening this year]. In the looming plug-in battle royal, whose electric/combustion technology will carry the day?

Toyota has bet 10 years, untold billions, and its future product direction on what's called the power-split hybrid. It has essentially the same design as mechanical-drive cars but uses both combustion and electricity for power, optimized by control algorithms. Toyota's plug-in version of the power-split hybrid has a bigger battery and can be recharged from a regular household power outlet. It runs short distances on electricity only, and then the combustion engine switches on, powering the car along with the batteries.

GM, on the other hand, is staking its long-term direction on the series hybrid, which can also be recharged from a wall outlet. The car runs on full electricity until its batteries are nearly empty, and then its combustion engine starts up to run a backup generator that recharges the batteries. Unlike the power-split hybrid, its combustion engine only charges the batteries and never actually powers the car itself.

Many of the challenges that thwarted the EV1 are still in play. These cars will use advanced large lithium-ion batteries, so battery life and safety remain serious concerns. And some new studies suggest that plug-in hybrids could pose significant pollution and resource problems of their own, largely depending on how the electricity to recharge them is generated.

As always, problems present opportunities, such as new roles for electrical engineers in power-train technology and in finding unconventional ways to support the modern auto's power-intensive onboard electronics. EEs have already edged into mainstream auto design as regulations have called for the sophisticated electronic control of everything from combustion management to vehicle stability.

Silicon Valley has joined the fray. Bellwether Google has a project to convert hybrids to plug-in hybrids. Other Valley-based start-ups are making high- and low-end all-electric cars.

So perhaps the world's car culture is now ready to head for greener car pastures, particularly if those pastures are filled with affordable, easy-to-use alternatives.

Both Toyota and GM plan to lay out their plug-in positions at the SAE 2008 World Congress, in Detroit, later this month (see http://www.sae.org/congress). For the auto industry, picking the winner is critical. Tens of billions of dollars, and perhaps even world automotive domination, are at stake.

—JOHN VOELCKER

forum

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GPS À LA CARTE

REGARDING "NO Payoff for Galileo Navigation System" [January]: to continue with the restaurant metaphor, there may be many Europeans who think that, instead of being invited to "Chez Gaston" (the U.S. Global Positioning System), they are merely getting a humanitarian daily ration (HDR) from the U.S. Department of Defense, intended only to provide sustenance to a moderately malnourished individual—useful for surviving but not for satisfying Europe's current demands. Promoters of the European geopositioning system (Europe's own "French restaurant in New York") intend to offer a wide menu for all tastes, including *"service ouvert à la fréquence unique"* (open service at a single frequency, similar to the HDR) but also *"SO à la double fréquence"* for vegetarians and *"SO à la triple fréquence"* for gourmets. The European advocates of this second "restaurant" do not intend to take away Gaston's business (the HDR is gratis!); they want only to improve their diet.

FRANCISCO CANCILLO, *IEEE Member, Madrid*

Senior Editor William Sweet responds: *Being a tech gourmet, in my future trips to Europe I will indeed look forward to using Galileo's special "open service at triple frequency." But I don't expect such premium services to ever pay for Galileo, and nor do Galileo's own backers. That's partly because it's only a matter of time till the Chinese restaurant next door offers such special geopositioning services. This is why Galileo does not make sense as a business proposition and needs to be radically reconceived.*

THE E-JOURNAL IS HERE

HAVING READ "Technical Publications and the Internet" [Reflections, January], I note that real-life examples exist that support Robert W. Lucky's vision of quality assurance for technical publications on the Internet, such as *Atmospheric Chemistry and Physics* (*ACP*) (http://www.atmos-chem-phys.net), published by the European Geosciences Union since 2001. Manuscripts are first published as "discussion papers" on the journal's Web site, where for a period of eight weeks referees (who may remain anonymous) and other members of the scientific community can post their comments. The editor then weighs the referees' comments and decides whether the paper should be published in the free online journal, which is financed through moderate author charges.

RICHARD SIETMANN
IEEE Member
Berlin

ON THE RECEIVING END

YOUR ARTICLE on wireless devices using the 60-gigahertz portion of the spectrum ["Gadgets Gab at 60 GHz," February] was very informative regarding the transceiver technologies under development at these frequencies. However, your characterization of the 57- to 64-GHz portion of the spectrum as "unlicensed" is inaccurate. Both the U.S. frequency allocation chart and the International Telecommunication Union regulations show allocations in this frequency range for several important services, including the Earth Exploration Satellite Service (57 to 59.3 GHz). The service is particularly sensitive to interference, given the use of passive microwave sensing at these frequencies for measuring atmospheric temperature information. Such measurements are enabled by the strong absorption of atmospheric oxygen in this frequency range.

JOEL T. JOHNSON
Columbus, Ohio

BUILD YOUR OWN DREAM AMP

READERS OF your Dream Jobs article on Bruno Putzeys and his Class-D amplifiers may be interested to know that they can learn how to build their own UcD at http://www.nxp.com/acrobat_download/usermanuals/UM10155_2.pdf.

KEN MARDLE
Auckland, New Zealand

CORRECTIONS

In the Dream Jobs profile of Mark Schubin [February], the "Fun Factors" caption should have put Tromsø, Norway, 400 kilometers north of the Arctic Circle.

Due to space considerations, Davide Pandini's quote in "The Ultimate Dielectric Is...Nothing" [January] was truncated. Pandini contended that although IBM's Air Gap technology research is promising, "perhaps comparable performance improvements could be achieved with mainstream interconnect technology by focusing the design efforts on new interconnect structures and on-chip communication paradigms, without changing the manufacturing process."

BRYAN CHRISTIE DESIGN

update

more online at www.spectrum.ieee.org

New Water Technology Headed for Parched Places

Capacitive deionization to debut in drought-struck Australia

NEXT MONTH an Australian-led coalition is expected to unveil a project to build experimental water-purification reactors in drought-plagued northeastern Australia. Parched cities in Queensland and New South Wales are turning to capacitive deionization (CDI), an electric field–based water desalination technology that could make inland water desalination much more affordable. CDI has long been stuck in laboratories and ignored by municipalities, which have preferred a mechanical method called reverse osmosis. But worsening inland droughts, massive private funding, and an international research effort are giving the alternative desalination technology its big break. CDI's backers say it will be on the market in 2009.

The dominant desalination technologies rely on membranes that frequently need replacement and cleaning. The most common, reverse osmosis, filters impurities by pushing pressurized water through a membrane. Another uses an electric field to drive the ions across a membrane.

CDI, in contrast, needs no membrane. In water, salts are dissolved as positively charged and negatively charged ions. CDI streams water between pairs of two oppositely charged porous electrodes. The negative ions drift into the pores of the positive electrodes and the positive ions drift to the negative, leaving pure, deionized water. Once the electrodes are "full," the reactor is stopped. The polarity of the electrodes is then reversed, and the ions are repelled. The ions are then flushed out of the reactor, flowing into a waste stream of supersalty brine.

Hoping to increase the electrodes' ion capacity and thus improve CDI's economics, Lawrence Livermore National Laboratory built the electrodes out of conductive carbon aerogel, a material with a surface area about 260 million times its volume (a grape-size piece has the surface area of two basketball courts). The aerogel's pores trapped huge

SPARE SOME WATER, MATE? Brisbane, Australia, and surrounding areas are experiencing a severe drought. The region plans to try a new desalination technology, capacitive deionization, to make its brackish water drinkable.
PHOTO: JONATHAN WOOD/GETTY IMAGES

update

numbers of ions before they were saturated, but they were also prone to clogging up with bacteria, which feed on organic particles in the water.

Bob Campbell, CEO of California-based Campbell Applied Physics, which is managing the Australia project, tackled the problem. With funding from Malta-based Water Resources International, Campbell worked with four U.S. Department of Energy national laboratories, among them Lawrence Livermore. The team developed a proprietary ozone technology that kills the bacteria before they can fill the aerogel's pores, says Lawrence Livermore technologist Bill Daily, who is developing the deionization reactors for the Australia project.

Northeastern Australia will be the first to commercialize CDI because of the proximity of parched cities to coal-bed gas mines, where pressurized underground water is used to release the trapped gas. The by-product is water that, though ample, is too brackish even for most agricultural uses. Many in the water industry have predicted that Australian demand for water-purification technology will spike as the mining industry taps the deep coal deposits in Australia's largest aquifer.

The reason reverse osmosis has dominated the market, and hence discouraged research into other methods, is that municipalities wanting water desalination have usually been coastal: huge desalination plants are built on shorelines in the Middle East, China, California, and Texas.

SOLID SMOKE: Superporous carbon aerogels are CDI's secret.
PHOTO: JPL/NASA

Where the water's salt content is high—it's about 32 000 milligrams per liter in ocean water—reverse osmosis is efficient and cost-effective. But for inland brackish waters, in which there might be 800 to 3500 mg/L of salt, CDI requires less energy, says Frost & Sullivan analyst Afamia Elnakat.

Until recently, opportunities for inland desalination were scarce because, as Elnakat says, "the water problem just hasn't hit anyone in the pocket yet." But inland droughts are starting to become ruinous. In the past two years, water levels in northeastern Australia have dropped to one quarter of their normal depth, causing barley and wheat production to plummet (and contributing to the country's decision to sign onto the Kyoto climate agreement). Similar long-term droughts have laid waste to water supplies in China and in the southwestern United States.

In these situations, CDI is a clear winner, argues Campbell. Its main efficiency advantage versus reverse osmosis is that it doesn't need pressurized water. CDI can also save power by allowing for "dial-in" ion concentrations: for medically pure water, for example, the reactors can remove all dissolved ions; but for agriculture the water can be somewhat saltier. The fewer ions that need to be removed, the longer the reactors can go between rinses.

And deionization might play a role in seawater desalination too. The World Health Organization warns that the natural boron content in seawater has been linked to developmental and reproductive disorders. Boron ions can slip through reverse osmosis systems. Campbell says that CDI can be a postosmosis "polishing" step to filter the boron.

—SARAH ADEE

WHAT ARE THE CHANCES?

MARTIN HELLMAN, professor emeritus at Stanford, used engineering risk analysis methods to determine the failure rate for the United States' nuclear deterrence strategy and came up with a shocking 1 percent chance per year that a nuclear war will break out.

More at http://www.spectrum.ieee.org/apr08/deterrence

JEFF TOPPING/THE NEW YORK TIMES/REDUX

$64 million The amount slashed from the supercomputing and advanced networking budget of the U.S. National Science Foundation for the 2008 fiscal year

Magnetic Field Sensors Could Help Halt Runway Crashes

European engineers harness Earth's magnetic field to improve airport safety

AIR-TRAFFIC CONTROL is a complex and high-stress business. Mistakes are not allowed. And it's not limited to directing planes for takeoff and landing—a job that's been memorably described as three-dimensional chess. It also includes keeping track of where planes are on the ground. According to safety watchdog Eurocontrol, in 2005 alone there were 600 occasions when people, cars, or planes crossed Europe's airport taxiways when they shouldn't have. In fact, the most deadly airline accident ever happened on the ground: in 1977, two 747 jumbo jets collided in the Canary Islands, killing 583 people.

Most big airports have expensive ground-radar systems to keep track of where the hundreds of moving planes are on the sprawling tarmacs. But ground radar sometimes reflects off buildings and terminals, leaving small gaps in coverage. Smaller airports like the one in Thessaloníki, Greece, can't afford ground radar. Such blind spots on the ground at airports large and small have prompted European researchers to explore the use of fluctuations in the Earth's magnetic field to better pinpoint where planes are on busy taxiways. The results, researchers say, show that using US $150 sensors can fill in the blind spots.

Aerospace engineers and physicists in Greece, Germany, the UK, and Austria came together to build and test the cigar box–size magnetic sensors. The basic components of each sensor are a small memory chip, a magnetoresistive sensor, and a signal processor. The sensing element consists of a thin nickel-cobalt film over a silicon wafer. In this case, the wafer is set up like a resistor. An electric current is passed through the wafer so that when an external magnetic field is applied to the sensor or ripples in a field wash over it, the value of that resistance changes ever so slightly.

The quantity of ferromagnetic metal in an aircraft introduces disturbances in the Earth's magnetic field in the nanotesla range. The sensor can distinguish the disturbance left by a moving aircraft on the ground from background noise and other objects well enough to pinpoint not only the location of the disturbance but also the cause.

Engineers at Saarland University in Saarbrücken, Germany, working with local electronics firms, made a version of the sensor that can be mounted in existing taxiway light housings and runways. The Earth's magnetic field is not affected by buildings, fog, or rain, so the sensors just have to look for the right fluctuations, says Saarland experimental physicist Haibin Gao. That means the sensors work in the crevices where radar might not and see through weather that would blind a camera-based system. Each sensor covers about a 50-meter range. Gao says it would be too much trouble to cover a big airport like Frankfurt with hundreds of these sensors; still, they would be needed only at key points and to fill radar gaps in order to be effective. Smaller airports with one or two runways, however, could distribute enough for complete coverage.

Test results from Frankfurt and Thessaloníki are encouraging, says Nikolaos Grammalidis, a researcher at the Informatics and Telematics Institute, whose team, based in Thessaloníki, developed the sensor's filtering software. Grammalidis says that more filtering research needs to be done to account for, say, a large car passing at a considerable distance from the sensor, which might produce a signal similar to that of an airplane. But Saarland's Gao says the magnetic-field sensor is poised to be a relatively inexpensive step in improving the picture of air traffic on the ground. —MICHAEL DUMIAK

DELAYS AHEAD: Controlling air traffic on the ground could be made easier by sensors that determine where aircraft are by the disturbance they make in the Earth's magnetic field.
PHOTO: ANDY CAULFIELD/GETTY IMAGES

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CRUSHER, the autonomous vehicle funded by the U.S. Defense Department and built by Carnegie Mellon University, lived up to its name during urban and desert field trials at Fort Bliss, Texas. Crusher not only drives itself, but unlike other unmanned vehicles it also sketches out real-time maps of the terrain by using laser range finders, radar, and stereoscopic optical cameras. Watch Crusher crush things (and maneuver around things that don't crush well) at http://spectrum.ieee.org/video?id=241 PHOTO: SARAH ADEE

update

Carbon-Nanotube Wiring Gets Real

With a need to replace copper chip interconnects in sight, a potential successor is finally proving itself

COULD CARBON nanotubes have a shot at replacing the copper wires that connect millions of transistors on today's silicon chips? Chip makers replaced aluminum interconnects with better conducting copper ones about seven years ago, but now copper's days are numbered too. Higher-performance chips with more-tightly packed transistors, expected as soon as 2012, will need interconnects less than 40 nanometers wide, at which point copper's resistance will slow signaling down too much.

Late last month, at the Materials Research Society's spring meeting in San Francisco, a team of engineers from Stanford and Toshiba reported that they have used carbon nanotubes to wire logic-circuit components on a conventional silicon CMOS chip. They claim to have shown that nanotubes can shuttle data at speeds of a little faster than 1 gigahertz, close to the range of state-of-the-art microprocessors, which run at speeds of 2 to 3 GHz.

In principle, nanotubes can handle a current density 1000 times as great as that of copper or silver. Accordingly, many chip makers, including Intel, have been trying to figure out whether nanotubes can be practically combined into an integrated circuit and, if so, how their properties hold up.

Stanford electrical-engineering professor H.S. Philip Wong and his collaborators at Toshiba fabricated common test circuits, called ring oscillators, on a silicon chip. Each oscillator was missing one wire that would complete the circuit. Then researchers laid down nanotubes on top of the circuits to make that last connection. Of the 19 ring oscillators, 16 worked at over 800 megahertz, and the best worked at 1.02 GHz. "This is the first time that a nanotube as a wire is operating in a conventional chip-type environment," Wong says.

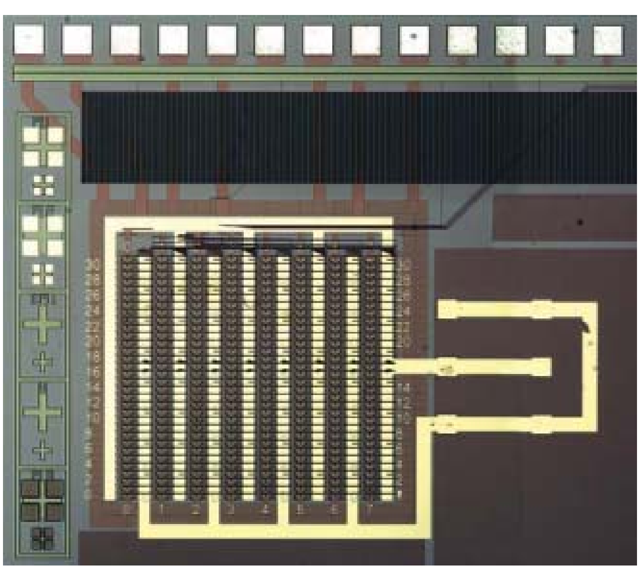
Alexander Tselev, a chemist studying carbon-nanotube interconnects at Duke University, in Durham, N.C., hails this as "a step from basic science to real application." Still, a number of big challenges remain, particularly devising a reliable method to make nanotubes with consistent properties and finding a good way to arrange tubes in a pattern.

Today's manufacturing processes result in batches containing nanotubes of different sizes and electrical properties, some that conduct electricity and others that are semiconductors. Indeed, it is the inconsistencies in resistance and in the length of the nanotubes that result in the different operating speeds of the ring oscillators, Wong says.

There is also no known way to precisely place nanotubes on a surface. The researchers use a standard method called dye electrophoresis. It involves depositing a nanotube solution on a surface and applying electric fields to attract the nanotubes to the required spots. The method is unpredictable. Wong and his colleagues started out by fabricating 256 oscillators; carbon nanotubes completed the wiring in only 19.

There are many other problems to be solved. Interconnects would need to be made from bundles of carbon nanotubes, because they conduct current much better than single nanotubes do. But bundles of tubes would be hard to lay down horizontally. Unlike integrated circuits, which have layers of semiconductor, insulator, and other materials "nicely stacked one on top of the other," says Vladimir Stojanovic, an electrical-engineering and computer-science professor at MIT, "tubes are hard to handle, because they don't stack up very well." Manufacturers will have to find either a way to place prefabricated nanotubes in the right spots or a way to grow nanotubes where they're needed at temperatures that match silicon-fabrication temperatures, Stojanovic says.

Clearly, carbon-nanotube researchers have a lot left to do. With copper needing a replacement as soon as 2012, they might have to speed things up. —PRACHI PATEL-PREDD



TUBE TESTER: Carbon nanotubes in this 256-oscillator circuit operated at about 1 GHz. PHOTO: GAEL CLOSE

GPS Signals Spot Signs of Typhoons

The COSMIC satellite constellation uses GPS signals for a vertical view of the atmosphere

THE COSMIC constellation—a set of satellites that improbably exploits signals from the U.S. Global Positioning System to obtain atmospheric data—is aloft after a rocky start and is producing readings that improve weather forecasts and climate models. Since the satellites' launch in 2006, three have experienced serious malfunctions. One lost a solar panel and is still working at reduced capacity, while another lost its solar-panel drive mechanism, leaving the panels stuck in one direction. A third mysteriously took a prolonged vacation for two months but just as inexplicably came back to life again last November.

Even so, forecasters already have come to appreciate COSMIC's high-quality vertical views of the global atmosphere from the ionosphere down into the troposphere, to within 1 kilometer of Earth's surface. A single sounding from a COSMIC satellite helped predict the formation of Hurricane Ernesto in late August 2006, which killed eight people and caused more than US $500 million in damage.

"The COSMIC data are unique," says Stephen Lord, director of the U.S. National Oceanic and Atmospheric Administration's environmental modeling center, which uses the satellites' soundings of temperature, pressure, and humidity for global weather forecasts. "They measure the atmosphere in a way that no other instruments measure it."

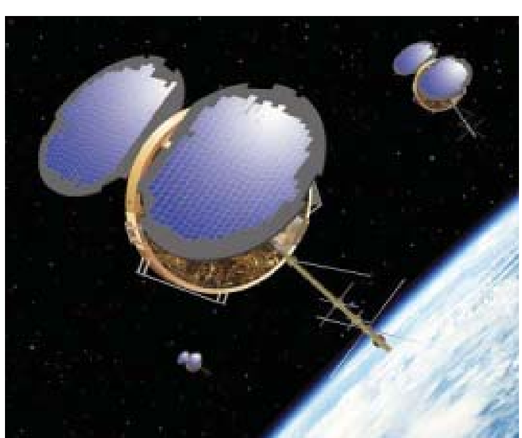
COSMIC, or Constellation Observing System for Meteorology, Ionosphere, and Climate, is a collaboration between the University Corporation for Atmospheric Research (UCAR) in Boulder, Colo., and the government of Taiwan. Its primary goal is to demonstrate the predictive powers of a new technique called near-real-time radio occultation [see "Roundabout Way of Profiling Earth's Atmosphere," *IEEE Spectrum*, April 2006]. As the six COSMIC satellites travel in low-Earth orbit, they pick up radio signals from the 28 civilian GPS satellites in higher orbits. COSMIC's receivers measure changes in the frequency of the GPS radio signals, as the COSMIC and GPS satellites rise and set relative to each other. The frequency changes reflect changes in atmospheric conditions.

A number of weather centers have been able to make measurable improvements in their accuracy using data from COSMIC, including the National Centers for Environmental Prediction in the United States, the European Centre for Medium-Range Weather Forecasts, Britain's Met Office, and Météo France, says Richard Anthes, who conceived the COSMIC mission and is the president of UCAR. "The improvements are especially remarkable, given the relatively small number of COSMIC data compared to other sources of weather data," he says. From September 2006 to August 2007, the COSMIC constellation provided more than 730 000 lower atmospheric and 1 005 000 ionospheric weather profiles to 610 weather centers around the world.

As expected, COSMIC has been particularly useful to East Asian countries like Taiwan that are exposed to devastating typhoons. The satellites have helped predict cyclonic storms over areas of the Pacific and the South China Sea where weather data are otherwise sparse, says Chris Rocken, a UCAR lead scientist for COSMIC.

"We are still learning how to use COSMIC data in an optimal way," says Anthes. With luck, the battered bunch of satellites will last long enough for that and maybe make it through to finish their mission in 2011.

—BARRY E. DIGREGORIO



EYES IN THE SKY: The COSMIC satellites [right] use GPS signals to help predict storms like Typhoon Krosa [top], which tore into Taiwan last year.
ILLUSTRATION: ORBITAL SCIENCES CORP.

SAM YEH/AFP/GETTY IMAGES

news brief

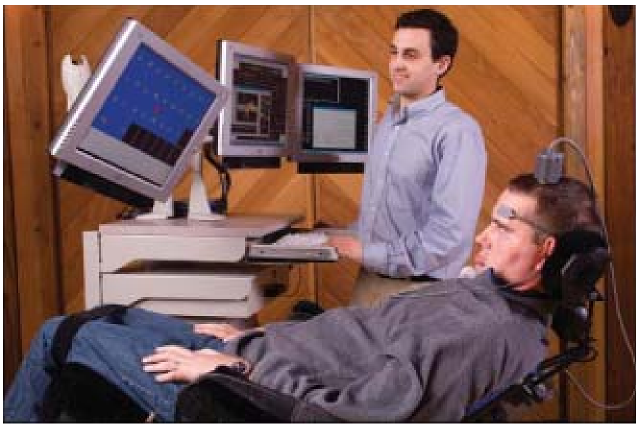
DOOMSDAY VAULT

On 26 February, an underground vault intended to store samples of the world's seeds in case of a global disaster began accepting deposits. The vault, on the Norwegian island of Spitsbergen, is designed to hold samples of up to 4.5 million types of seeds for hundreds or even thousands of years. A coal plant powers a refrigerator in the vault that keeps the seeds at about –20 °C, but even if the power should fail, the vault's temperature will rise only to –3 °C. The eerie green glow at the entrance comes from an art installation made up of 200 optical fibers.

PHOTO: MARI TEFRE/GLOBAL CROP DIVERSITY TRUST

9.0 The magnitude of an earthquake striking Seattle in a simulation at the San Diego Supercomputing Center. The city sits on top of a sediment-filled basin that may amplify seismic waves

update



PLUGGED IN: Algorithms interpret brain signals to move a cursor on a screen.
PHOTO: MATTHEW MCKEE/CYBERKINETIC NEUROTECHNOLOGY SYSTEMS

Standardizing the Brain-Machine Interface

Every neural-prosthetics lab has its own brain-decoding algorithm, but could one size fit all?

EARLIER THIS year in a lab at Duke University, in Durham, N.C., a clever, raisin-gobbling monkey named Idoya made a robot move in Japan—just by thinking. And she wasn't alone. She joined ranks with, among others, a paraplegic man who recently used his brain to move a cursor around a computer screen.

Researchers have endowed subjects with seemingly telekinetic powers by extracting the patterns of brain activity that occur when we move parts of our bodies. However those patterns are tapped electronically, algorithms are needed to interpret them and discern their salient features so that the appropriate signals can be sent to external devices. Groups working on brain-machine interfaces have designed brain decoders differently, depending on the type of neural data they collect and the purposes of their research. As a result, most algorithms have to be written from the ground up. But some in the field say it's time to develop a generic algorithm that will incorporate the best work of the last decade and serve as a foundation for all labs working on neural prosthetics.

That's just what Lakshminarayan Srinivasan, a computer scientist at MIT, has in mind. Srinivasan—together with colleagues at MIT, Harvard, Boston University, and Massachusetts General Hospital—has pulled together elements of algorithms from all the major labs that design brain-machine interfaces and proposed a new approach that theoretically would support and enhance each design.

From the outset, researchers attacking the mind-over-matter problem of developing brain-activated prosthetics adopted widely varying approaches. Some pasted electrodes onto the scalp; others placed them just inside the skull or directly into the brain. They eavesdropped on different parts of the brain and, having obtained signal patterns, processed them differently, says Srinivasan.

There are many ways to filter neural data. When users imagine moving a cursor on a screen, for example, they produce data about the speed they want it to go, where and when they want it to stop, the route they want it to take, and when it should click. At any point, their intentions might change. Also, over longer periods of time, neurons may die and replace one another in ways that can alter the signal. Every algorithm takes into account some of those dynamics, but none yet incorporates all of them, as Srinivasan is doing.

Srinivasan has developed his algorithm even as brain-machine interfaces are moving from the lab to the clinic. Already, Cyberkinetics Neurotechnology Systems, in Foxborough, Mass., is conducting clinical trials for a device called the BrainGate Neural Interface System, which would give severely paralyzed patients the ability to communicate through a computer. The first subject, a fully paralyzed man with amyotrophic lateral sclerosis, had a 100-electrode array implanted into his motor cortex. "The very first day he tried to use the device, he had some control over the computer cursor," says Leigh Hochberg, the principal investigator on the trials.

Despite early successes, researchers at Cyberkinetics consider the algorithms a work in progress. "We adjust it all the time," says John Simeral, an electrical engineer at Brown who works on the BrainGate algorithms.

Simeral says that elements of the algorithm Srinivasan suggests could further improve the BrainGate cursor task. For example, the system could give a clearer estimate of the exact moment a person radically changes intention.

In simulations, Srinivasan's algorithms performed as well or better than those he sought to unify. But Mikhail Lebedev, an engineer in Miguel Nicolelis's lab at the Duke University Medical Center, says you can't ultimately use simulations to judge an algorithm. When people plug into brain-computer interfaces, it's not only the algorithms that adjust to the way the brain works. The brain, to some extent, also learns how to manipulate the rules of the algorithms to get its desired outcome, and so you can never fully predict how the algorithms will perform.

Srinivasan says he's now learning electrophysiology techniques and will soon try out his algorithms on human subjects. —MORGEN E. PECK

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the big picture

GONE TO PIECES

The dancer pictured here has not been blown to bits. But an Australian dance company, with an assist from German computer engineer Frieder Weiss, made it seem that way during a recent performance at the Sydney Opera House. Weiss has created a computer program called EyeCon that can cause even the most observant audience members' eyes to deceive them. EyeCon translates a dancer's movement and position on the stage into real-time reactive video projections. The special effects can make the dancers appear to float, shrink, grow, disappear, or in this case, disintegrate.

PHOTO: GAYE GERARD/ GETTY IMAGES

 BY PAUL MCFEDRIES

Of Geeks, Modders, And Overclockers

"The B3-stepping Q6600 carried the S-Spec SL9UM, while the new G0-stepping part has the new SLACR S-Spec."
—Anand Lal Shimpi, technical writer and CEO of *AnandTech*

LAURENT CILLUFFO

THIS CRYPTIC snippet comes not from a technical manual or an electrical engineering paper but from a mainstream computer magazine called *Computer Power User* (known, inevitably, as *CPU*). What's such geeky gobbledygook doing in a magazine that's available in grocery stores? I think it's a reflection of a surprising fact that's recently come to light: geeks are big business. Magazines like *CPU, Maximum PC, PCXL,* Australia's *Atomic*, and even some sections of good old *Popular Mechanics* are aimed at the hard-core geek market. These mags, and their online cousins, such as *AnandTech* (http://www.anandtech.com) and *Tom's Hardware* (http://www.tomshardware.com), don't even pay lip service to beginners.

It's a fascinating genre, particularly for the language watcher, because the **alpha geeks** who write for these magazines and sites, as well as the **beta geek** civilians who chime in with their letters and forum posts, have a unique, fun vernacular. The focus is on people who either put together their own computers—the **builders**—or customize the physical or electronic characteristics of existing computers—the **modders**.

Many of the latter spend countless hours tweaking their computer systems to increase the standard processor clock speed (known as the **stock clock**), so they're often called **overclockers**. They regularly use **overclock** (or just **oc**) as a verb and will describe an easily tweaked system as **overclockable**. If they manage to crank up the gigahertz to some extraordinarily high (and probably dangerous) level, these **extreme overclockers** say that they've **superclocked** the system. Another popular **mod** is to **overvolt** the processor for faster performance, a practice often called **volt modding**. Of course, if you go too far with all this, you'll kill, or **brick,** the part.

A less dangerous practice involves painting, etching, **Dremeling** (yes, your favorite rotary tool is now a verb), and otherwise tricking out a computer's outsides, a practice called **case modding**. Specific **case mods** include the **paint mod** (a custom paint job; if you paint just the front, it's a **bezel mod**), the **case tattoo** (an image etched into the case or an appliqué stuck to the side panel), the **window mod** (cutting a hole in the side panel and covering it with acrylic or some other transparent material), **backlighting** (adding interior lights so you can see through your window mod at night), the **blowhole** (cutting a hole in the top of the case so that you can add another exhaust fan), and the **case badge** (a 2.5-centimeter-square piece of metal with a logo or other image that you attach to the case).

In this world, a computer isn't a "computer," no, sir. It is instead a **box** or, more often, a **rig**, as in "I overclocked and overvolted my processor, and now my rig is melting. Please help!" Got a particularly exciting game that you like to play? Then feel free to describe it as **rig-rocking**. Did you cobble the machine together from scavenged parts? Then call it a **Frankenrig** (or a **Frankenbox**).

As hackers have always done, builders and modders shed syllables as easily as dogs shed fur. So a CPU, or processor, becomes a **proc**; a motherboard becomes a **mobo,** or just a **board**; product specifications become just **specs**; and next-generation is always **next-gen**. Not surprisingly, initialisms abound in this world: **CPU** (central processing unit), **GPU** (graphics-processing unit), **PPU** (physics—or **physx**—processing unit), and **PSU** (power supply unit), to name just those that involve the word *unit.*

The world of hard-core builders and modders is one in which **fanboys** (also **fanbois**—overly dedicated fans of a component or manufacturer) endlessly debate the merits of their favorite parts, **sysspecs** (system specs) are the most common signature in forum posts, and **mod galleries** show off outrageous designs. It's a world in which the *positive* adjectives of choice are **sick**, **killer**, and **monster**. It's a world that's occasionally incomprehensible but always passionate and creative—an endless source of mods of the linguistic variety. ❑

careers

SO YOU WANT TO BE AN EXPERT WITNESS

Roger L. Boyell says forensic engineering is a great job—if you can take the pressure

ROGER L. BOYELL has narrowly escaped getting run over by a mobile crane, had rifles pointed at him while investigating an airport radar facility, and has been nearly asphyxiated in an abandoned photo lab. Then there was the time he had to climb a slippery ladder to an electrical panel above a giant sewage tank.

"I needed two hands on the ladder, another on my camera, another on my briefcase, and another holding my nose," Boyell laughs. "What went through my mind was 'hazardous-duty pay required.' "

He's part of a growing cadre of engineers who are trading steady paychecks and corporate environments for the often solitary and occasionally adrenaline-inducing position of expert witness. It's their job to evaluate engineering systems, products, and devices and explain them in layman's terms in a courtroom.

Boyell, an IEEE senior member, has a bachelor's degree in electrical engineering, a master's in applied science, and an MBA. It all testifies to a generalist's training that he says finally made him "a dinosaur" in his previous bailiwick, the defense industry.

It turned out, however, to be the perfect background for a forensic expert."I still use things I learned as a college freshman and sophomore," he says. "Heat transfer, mechanical advantage, electricity, and magnetism—but applied to real-world problems."

To make it in this business, you have to know a lot about something and a little about nearly everything else. "Qualifications have become more demanding for experts, as criteria for what's admissible as evidence have tightened up," says Marvin Specter, executive director of the National Academy of Forensic Engineers. Some states require that experts have professional licenses.

ELEMENTARY? Roger L. Boyell solves legal puzzles by taking his engineer's bag of tricks [below, left] into the field. PHOTOS: BILL CRAMER

In 1978, after 20 years developing acoustic tracking and electronic warfare systems in Philadelphia, Baltimore, and New York, Boyell got his first taste of forensic work when an attorney tapped his expertise for a case involving civil radio communications. He turned the gig into a regular sideline, consulting with clients after work and during personal and vacation days. Finally, in 1998, he became a full-time, self-employed consultant.

Forensic experts can earn as much as lawyers. Boyell charges $200 an hour, working anywhere from 20 to 80 hours a week, though only about half the time he spends on his business is billable. There's marketing, advertising, bookkeeping, professional seminars, and other overhead.

The work is not to everyone's taste. Even before testifying, a forensic engineer must undergo a rigorous oral examination by the court to ascertain his level of expertise in the pertinent subject matter. Then he gets grilled by lawyers for the opposing side.

"If an adversarial lawyer can't demolish your technical argument, he will attack your personal credentials," Boyell says. "You have to be prepared to defend everything in your life that's been on the public record—even this article. It feels like a combination of defending your thesis and interviewing for a new job. But there's a real satisfaction in knowing you contributed to the resolution of a contentious matter," he adds.

However, unlike cases in the television show "CSI," real-world cases don't always end neatly. "It starts as giving advice, then writing reports, and ultimately, you might be deposed or take the stand during a trial. Sometimes that process can take years, and then it's usually the big-money suits and criminal cases. But that happens in a fraction of the cases. Usually, my report ends the matter."

An expert must put his client before himself but his professional ethics before even the client. His first duty is to the truth. In one case, Boyell was hired to prove that a hardware defect caused an electrical fire. Not only did he find no evidence of a defect, but he uncovered an errant extension cord that suggested the hardware in question wasn't even involved.

"If my findings are adverse to what my client wants me to tell them, that's the end of the job," he says. "But my real job is to stay objective." —Susan Karlin

AN ENGINEER WALKS INTO A COMEDY CLUB...

Electrical engineer Don McMillan has turned his love of comedy into a career

Don McMillan likes to say that the only time people laugh at engineers is when they mess up at work. But he's the exception. He's a trained electrical engineer, and people laugh at him every day—*unless* he messes up. That's because he tells jokes for a living.

He had his first big success in 1993, when he won US $100 000 on "Star Search," the TV talent show. Now he tours the country doing gigs for corporate audiences, for which he tailors specific acts. He calls himself an ASICC: an Application-Specific Integrated Comedy Consultant.

McMillan may be the only comic in the world who uses PowerPoint. He got the idea when his improvised riff on a presentation marked by mind-numbing technical slides killed the audience. So he went home and designed slides with titles like "Baby Directional Falling Probability" and "Don's Chances of Winning an Argument."

In fact, he says his act now is less like traditional stand-up and more like a multimedia performance. His favorite show took place at the Smithsonian National Air and Space Museum, in Washington, D.C., where he projected his presentation onto an enormous IMAX movie screen. "I'm in the little corner of the slide," he recalls. "I felt like the paper-clip guy in Microsoft Office that pops up and goes, 'Hey, there's a faster way to do this.' I was the size of the font!"

As a kid, McMillan excelled at science and math, and engineering seemed to be the logical career path. "Nobody ever looks at your SAT scores and says, 'You should be a comedian,' " he jokes. So he earned bachelor's and master's degrees in electrical engineering and joined AT&T Bell Laboratories, where he was part of the team that designed the world's first 32-bit microprocessor, the BellMac-32. Then he spent six years at VLSI Technology, in San Jose, Calif., designing integrated circuits.

After work, he frequented comedy clubs. "In a typical engineering approach, I watched and noted mentally what worked and what didn't work and how comics did things," he says. He first performed at an open-mike night in 1986, and then for three years he led a double life—chip designer by day, stand-up comic by night.

McMillan performed frequently at a club in Sunnyvale, Calif., that got patrons from nearby companies like Sun Microsystems, Silicon Graphics, and Apple. Drawing on his engineering background, McMillan began telling jokes for his techie audience ("Silicon Valley, it's very unusual. It's the only place I've gone to a wedding and the couple was registered at Fry's Electronics"). The corporate gigs followed.

McMillan's Act is less like stand-up and more like a multimedia performance.
PHOTO: LAURA MCMILLAN

McMillan's humor transcends cultural borders, says Don Maulsby, senior vice president of sales at Mentor Graphics, who has hired McMillan to entertain at several worldwide sales meetings and customer events. "We have people from offices in 47 places around the world," Maulsby says. "His humor really resonates with our entire company. He really appeals to the high-tech crowds, but he can relate to just about anybody."

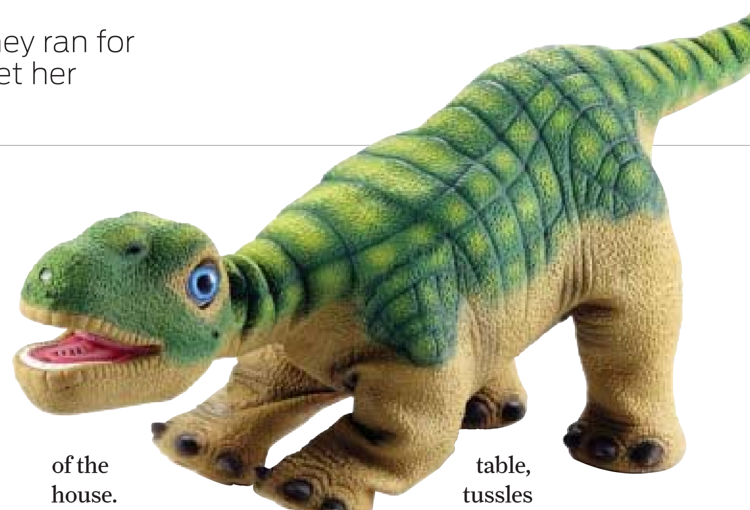
McMillan says his non-nerdy audiences are catching up with him. "I never used to be able to do any of my technical jokes in regular comedy clubs," he says, "but now everybody knows what a broadband line or wireless service is."

—Corinna Wu

TO PROBE FURTHER
See our video report at http://www.spectrum.ieee.org/apr08/comedy.

Our cats considered Pleo real and scary—they ran for cover whenever we tried to get them to meet her

tools&toys



Pleo, the Poop-Free Pet

Can Ugobe's robotic dinosaur replace the family cat?

When Pleo the robotic dinosaur moved in to my house for two weeks in January, my kids—ages 9, 12, and 16—were thrilled. They quickly decided that Pleo was a girl; I'll refer to her as one from now on.

The brainchild of Ugobe, a robotics company in Emeryville, Calif., Pleo looks and acts the way you'd expect a baby *Camarasaurus* to, thanks to sophisticated robotics. She has two 32-bit and four 8-bit microprocessors, fourteen motors, a camera, two microphones, eight sensors under her rubberized skin, a tilt sensor, an infrared mouth sensor, fourteen force-feedback sensors, and four switches in her feet. [See our video at http://spectrum.ieee.org/video?id=100.]

First, the good: the movement and sounds are indeed amazing. My daughter handed Pleo to a friend to cuddle, and Pleo nestled in and wrapped her tail securely around the friend's arm, completely freaking her out. Our cats considered Pleo real and scary—they ran for cover whenever we tried to get them to meet her.

Although her behaviors are set to be triggered by certain stimuli, at least one trick appeared to come at random (in any case, we never figured out how to elicit it): Pleo would hold up one front leg and one back leg, balance on the other two, and chortle. My kids called it the "yippee!" but I never got to see this one.

Now, the bad: battery life is a huge problem; ideally, you'd let Pleo have the run of the house. But if you leave her alone, she goes to sleep after a few minutes to conserve power. A full charge, which takes 3 to 4 hours to complete, will let her play continuously for about 40 minutes. Sometimes the battery overheated, cutting the sessions shorter still.

Then there's the price. Ugobe had originally planned to sell Pleo by Christmas 2006 for less than US $200, but the shipping date slipped to late last year, and the list price rose to $349. That busts the "cheaper than an iPod" price that many parents set as the limit for their children's toys.

Finally, Pleo has only a small bag of tricks. Though the behaviors are well conceived and implemented—she settles down to sleep, shies away from the edge of a table, tussles with the toy leaf included in the package, and explores new objects—there are too few to keep Pleo interesting.

When I first saw Pleo two years ago, at a conference for emerging technologies, I was impressed by Ugobe's claim that the dinosaur would develop a personality based on how it was treated. But now the company says it will provide most of that malleability only later, via free software updates.

Once I told my kids that Pleo didn't actually learn much from the way she was handled, they found the most interesting thing to do was to hold her upside down by her tail, making her scream and squirm. And then they would see how quickly they could calm her down and put her to sleep.

After a few days with Pleo, my kids lost interest and abandoned the dinosaur in a corner of the living room. So I took her to my office. There is something cozy, albeit strange, about having her wake up and roam around. She just discovered a chest full of electronic gear and is completely obsessed with it. I wonder whether she's programmed to bond with other gizmos.

My call? The folks at Ugobe may be onto something, but they're not there yet.

—Tekla S. Perry

ME, MY GENES, AND I

Most medical images are too obscure (think spleen) or all too clear (think brain) to appeal as art, but Ottawa-based DNA 11 has hit on the happy medium: your genes. The firm extracts DNA from your inner cheek, copies it, pulls it through an electric field to separate it into bars and blanks, and photographs the eerily glowing pattern in a color of your choice. *From US $390 (small) to $790 (pictured size); http://www.dna11.com.*

TOP: UGOBE; BOTTOM: DNA 11

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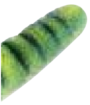


Hacking the Nokia N800

This handheld costs a tenth as much as an equally powerful desktop 10 years ago

SMALL? SURE, but the point is that the N800 is a full-blooded computer that a bona fide amateur can reasonably hope to program.
PHOTO: SHAYNE LYNN

A LOT CAN happen in a decade. You can hold the Nokia N800 in your hand, yet it's a near-exact match for a high-end desktop PC from 10 years ago. It has a 320-megahertz processor, 128 megabytes of RAM, and a few gigabytes of available mass storage. Although its screen displays only 800 by 480 pixels instead of 800 by 600, it's a touch screen, and the machine comes with IEEE 802.11g wireless-networking capability, which wasn't available in 1998 at any price. It's not the only pocket computer with such specs by any means, but it sure makes a good test bed for thinking about life 10 years hence, when PCs may well be printed on shirtsleeves.

If the N800 were a PDA, it would have a calendar/contact/to-do manager built in. It doesn't. If it were a smart phone, it would connect to cellular networks. It doesn't. Instead, you can wirelessly connect to Web-based versions of these tools. Or you can hack together your own programs.

Since the N800's predecessor was released two years ago, a community of thousands of hackers has grown up around it. We converge at Maemo.org, the Web site Nokia set up to support us. More than 300 open-source software projects are hosted there, with uncounted others elsewhere. And the N800's Linux-based foundation means that yet other masses of software—pretty much anything that doesn't need a graphical interface—can run unaltered.

I start with the basics—a calendar program—by downloading GPE, a suite that runs on pretty much any Linux box. However, synchronization to my Macintosh isn't really ready for prime time. There's a program (gpesyncd) you can run from a terminal window that will accept the vCal format the Mac uses and stuff items into the local database, but that's about it. The developers promise they'll get around to full sync eventually.

In the meantime, I could log into the N800 from my Mac, fire up gpesyncd, and paste each event into the terminal window by hand. But that would be too simple, and it would work for me only at my desk. Instead, I glue together a bunch of disparate tools: I'll e-mail events to the gizmo and sync from there.

On the Mac side, that's easy: I simply mail the event to an address that only the N800 will ever read. For the N800, I start with a special filter rule for the mail software to recognize an incoming calendar message and send its text to a program (as yet unwritten) that will, in turn, call gpesyncd. Here's where I learn how to write a little code in Python: first, I play around on the Mac and figure out the most concise way to extract the data. Then I shift over to IPython, a nice interactive Python development environment that runs on the N800, to code up the part that will talk to gpesyncd.

In short order, I have two terminal windows open from the Mac to the N800: one to play with code fragments and another to monitor interprocess activity and kill stuck processes when necessary.

Not too long after that, I have working code—and the good sense to stop. My information goes a dozen hops on the Internet from my Macintosh to some mail servers out of state, then another dozen hops back to my gizmo.

It's inefficient, but I don't care. Both computers have CPU cycles and bandwidth to spare, I've spent a few enjoyable evenings hacking, and I have a solution now instead of months from now. The mere fact that a tyro like me can cobble a solution together out of existing tools also gives me a glimpse of what the world might be like when pretty much any computer visible to the naked eye can be programmed (for better or worse) by ordinary users. —PAUL WALLICH

SOFTWARE USED ON THE MAC:
- Emacs
- Firefox
- Python 2.5
- Thunderbird
- IPython
- iCal

ON THE N800:
- Claws-mail
- JOE (Joe's Own Editor)
- Python 2.5
- gpesyncd to-gpe.py
- IPython
- GPE Calendar
- Bash

PETER DYLAN O'CONNOR

Mini-Profile
By Susan Karlin

MIKE DAISEY: ONE-MAN SHOW

Mike Daisey's "Monopoly!" may be the only nightclub act ever to center on the relative merits of alternating and direct current. In his monologue, Daisey describes the eccentric genius Nikola Tesla and his part in the feud with Thomas Edison over the two forms of electricity. In the process he explores corporate rule, life according to the dictates of profit and loss, the Microsoft antitrust lawsuit, Wal-Mart's impact on Daisey's hometown, and the secret history of the board game Monopoly. For more, see http://www.mikedaisey.com.

TOP 10 TECH CARS

IT'S THE ENVIRONMENT, STUPID

BY JOHN VOELCKER

WHEN A SEXY SILVER FERRARI F430 Spider has "Bio Fuel" emblazoned on the doors in bright green, you know the world has changed. Yet that was the sight at a major auto show early this year. As one industry commentator put it, "Green is the new black."

Consider that Europe is debating not *whether* to cut carbon emissions from vehicles but simply *when* to do it and by *how much*. The average new car on Europe's roads now emits roughly 160 grams of carbon dioxide per kilometer; the European Commission proposed last year to lower that to 130 g/km by 2012. But Europe's carmakers seem likely to have missed a voluntary 2008 target of 140 g/km.

This issue has pitted French and Italian carmakers—who specialize in small, fuel-efficient cars—against German manufacturers, who could see many of their luxury and sports-car products become problematic. Now a staggered set of weight-based limits may be instituted, and the deadline may be pushed all the way to 2015.

Carbon emissions are becoming a standard automotive benchmark in Europe and parts of Asia, but North American car buyers remain almost entirely unaware of them. To reflect the global discussion, *IEEE Spectrum* has included whatever numbers on vehicle CO_2 emissions we could obtain from the manufacturers.

Many of this year's innovations center on combustion-engine technology—Ford's EcoBoost turbocharged gasoline direct-injection engines, Mazda's tiny Miller-cycle engine, BMW's centrally mounted twin turbochargers. Then there's the diesel engine, which appears set for a revival following the fuel-economy regulations enacted late last year in the United States. Both European and Japanese carmakers are preparing to launch diesels in North America over the next two to five years. Even though the engine requires elaborate and costly emissions controls—like the Mercedes-Benz Bluetec system—to trap the great number of fine particulates diesels emit, their lower fuel usage and CO_2 emissions are unquestioned.

Will U.S. buyers go for diesels? No one knows. It may be the industry's biggest open question.

The plug-in hybrid electric vehicle is another puzzle. General Motors is expressing quiet confidence that lithium-ion batteries will clear the various hurdles needed for a late-2010 launch of its Chevrolet Volt extended-range electric car, projected to have a 64-km range on electric power alone. A plug-in version of GM's Saturn Vue Two-Mode Hybrid sport utility is due on roughly the same schedule, with a 16-km range. Toyota, meanwhile, abruptly changed its tune on plug-ins, launching a test fleet of Priuses converted to plug-in operation. It's a conversion that private customers have been ordering, one car at a time, at small garages across the United States and in other countries.

The trend extends even to China, where horrific air pollution and increasing dependence on imported oil threaten to muffle the country's economic boom. BYD Co., a Chinese battery company that claims to supply two-thirds of the world's nickel-cadmium batteries and 30 percent of its lithium-ion mobile-phone batteries, started making cars in 2002. In January it demonstrated a plug-in hybrid sedan with a claimed electric range of 96 km, which the company said would be offered for sale in small numbers—in China only—by the end of this year. That said, fewer than 200 plug-in hybrid cars are on the world's roads.

Finally, the industry is doing something about the weight of its products. Ford's EcoBoost V6 engine, for example, provides the power and torque of a much larger V8 with better fuel economy, lower emissions, and less weight. Even so, a fully accessorized EcoBoost weighs about half as much as an entire Tata Nano, from India, which at US $2500 is cheaper than the options packages for many cars. That low price, and planned production in the millions, make the Nano easily the most important launch of the year. It is feared by the global auto industry and eagerly awaited by millions of Indian families, who now often travel in groups of four or five on a single scooter. ❑

2009 CHEVROLET CORVETTE ZR1

PRODUCTION CAR

■ **POWER PLANT:** 462-kW (620 hp) supercharged 6.2-L aluminum V8 ■ **TRANSMISSION:** Close-ratio 6-speed manual; dual clutch ■ **CLAIMED FUEL EFFICIENCY:** Information not available ■ **CLAIMED CO_2 EMISSIONS:** Information not available ■ **MORE:** Chevrolet is very proud of the fact that the ZR1's power-to-weight ratio is better than that of the Ferrari 599, the Lamborghini LP640, and the Porsche 911 GT2.

FERRARI PERFORMANCE AT ONE-THIRD THE PRICE

In some ways, it's the antithesis of advanced sports-car design. It's got an engine up front, with only two valves per cylinder, and those valves are opened and closed with pushrods, just as they were in engines a lifetime ago. Parts of the body are made of fiberglass, a distinctly old-fashioned material compared with the aluminum, magnesium, and carbon fiber used by the Corvette's competitors.

And yet, the Chevrolet Corvette ZR1 does one thing very well: it carries two people as fast as possible, whether on straight or winding roads. The Corvette is the only U.S. volume car with ceramic brake rotors and a polycarbonate window in its hood that gives a peek at the intercooler. Chevrolet's goals are simple: maximize power, minimize mass.

Developed under the code name Blue Devil, the ZR1 is built around a 6.2-liter aluminum V8 developing 462 kilowatts (620 horsepower) of power and 807 newton meters (595 foot-pounds) of torque. The aluminum block has the dimensions of the classic Chevrolet small-block V8, but this one is hand-built at a special engine shop with processes used only for racing engines. For instance, a deck plate is installed on the aluminum block, to simulate the pressure and minute dimensional differences created by the cylinder heads, before the cast-iron cylinder liners are pressed into it.

A Roots-type supercharger crams air into the engine via an intercooler, providing a denser dose of oxygen that's nevertheless cooled down enough to fend off power-sapping premature combustion. Like most supercharged engines, it can deliver close to peak power over a wide range of engine speeds, from about 2500 revolutions per minute to 6600 rpm.

To handle all that power, the clutch uses a pair of smaller discs rather than the single plate of other Corvettes. This spreads the torque over a greater area and reduces inertia by 25 percent, letting the engine spool up or down more quickly. As with the highest-performance German cars, the ZR1's brake rotors are made of ceramic silicon carbide reinforced with carbon fiber, which is less susceptible to the friction-induced changes that can cause brake power to fade temporarily after repeated high-speed braking.

Ride control on the ZR1 employs a suspension of magnetic particles in a fluid instead of mechanical shocks. The viscosity of the fluid changes in response to a magnetic field, which varies every millisecond in response to inputs from sensors providing data on speed, suspension, and road surface conditions.

The roof, hood, front fenders, rocker panels, and some smaller parts are made of carbon fiber instead of steel, and the weight saved offsets the heavier engine. The car weighs just 1520 kilograms (3351 pounds).

Chevrolet hadn't released performance data by press time, but it said the ZR1 is expected to be the first production Corvette to exceed 320 kilometers per hour (200 miles per hour). It's rumored that the car accelerates from 0 to 100 km/h (62 mph) in less than 3.5 seconds. The factory did confirm that the cornering grip is more than 1 *g*—enough to make you feel twice your weight in a perfectly banked curve. That's among the highest *g*-forces of any production vehicle today.

At roughly US $100 000, the ZR1 bests cars costing two to four times as much. It's the only U.S. vehicle that routinely competes successfully in the fabled 24 Heures du Mans race, better known as Le Mans—heady company indeed for a car from Kentucky. ❑

AUDI METROPROJECT QUATTRO

CONCEPT

POWER PLANT: 110-kW 1.4-L turbocharged fuel-stratified injection engine; 30-kW electric motor **TRANSMISSION:** S-tronic 6-speed Direct-Shift Gearbox, a pairing of two manual gearboxes **CLAIMED FUEL EFFICIENCY:** 4.9 L/100 km (48 mpg) in mixed-mode operation **CLAIMED CO_2 EMISSIONS:** 112 g/km **MORE:** Minus the hybrid, the Metroproject is likely a preview of Audi's upcoming A2 subcompact.

A PLUG-IN HYBRID WITH ITS OWN MOBILE PHONE—AND THEN SOME

This small and handsome Audi concept contains a surprise that wowed the gadget lovers at the 2007 Tokyo Motor Show: the removable "Audi mobile device," which combines elements of the iPhone, a key fob, a media player, and a wireless security monitor.

You can make phone calls, view maps, listen to music, and watch videos on the bright red device, but you can also unlock the car, ensure you locked the doors, start the engine remotely (to warm it up on a cold day), and view what's going on inside the car via an interior camera (in case the kids—or thieves—take it for a spin).

The Metroproject is one of several European concept cars this year equipped with a plug-in hybrid-electric power train. Here, a lithium-ion battery pack provides an electric range of up to 100 kilometers (62 miles) at a top speed of more than 100 km/h. The 1.4-liter engine cuts in when the battery's charge falls below 20 percent of its maximum.

Multihole injectors deliver fuel directly into the combustion chambers, and the turbo has been tuned to deliver power across the range of engine speeds. This arrangement minimizes the "turbo lag" that usually comes when the turbocharger spools up to a speed that's fast enough to compress the air it delivers to the intake manifold. Audi claims that 80 percent of the engine's peak torque is available from 1250 revolutions per minute.

The Metroproject's Quattro all-wheel drive is delivered by a combination of engine and motor. The combustion engine, generating 240 newton meters (177 foot-pounds) of torque, drives the front wheels; a 30-kilowatt (40 horsepower) electric motor, which adds 200 Nm (147 ft-lb), powers the rear wheels.

Audi says the hybrid system provides 15 percent better fuel efficiency than you'd get by using the engine alone. With a top speed of 200 km/h (124 mph) and acceleration from 0 to 100 km/h (0 to 62 mph) in 7.8 seconds, the Metroproject is something of a "performance hybrid"—a concept that so far hasn't proven popular in the United States, currently the largest market for hybrids of all sorts.

Drivers can choose between "efficiency" and "dynamic" configurations, which vary the control settings for throttle mapping, shift points, suspension stiffness, and other systems. Such variable personalities within the same car are another increasingly common feature in concepts (and a few production vehicles). They offer the driver a choice among profiles that combine different settings for the car's various electronic control systems, usually maximizing fuel economy at one extreme and performance at the other. ❑

ALL PHOTOS PROVIDED BY MANUFACTURERS

MERCEDES-BENZ F700

POWER PLANT: 1.8-L four-cylinder 190-kW (255 hp) turbocharged homogeneous charge compression ignition engine **TRANSMISSION:** 7-speed automatic **CLAIMED FUEL EFFICIENCY:** 5.3 L/100 km (44 mpg) during cruising **CLAIMED CO_2 EMISSIONS:** 127 g/km **MORE:** The way Germans pronounce "DiesOtto" (the sounds just like "DeSoto." Daimler sold Chrysler (which owned DeSoto) this year, so shouldn't Mercedes-Benz pick another name?

A NEW TYPE OF ENGINE IN A RADICAL REINTERPRETATION OF THE BIG BENZ

Low and sleek, the styling of this highly conceptual study for a future full-size S-Class Mercedes-Benz is almost as striking as its tiny power plant: a 1.8-liter four-cylinder engine that combines the advantages of diesel and spark-ignition engines while avoiding the disadvantages peculiar to each.

First let's review: spark-ignition engines use a spark plug to ignite a vapor of gasoline and air, compressed at a ratio of perhaps 10:1, so that the burn starts at one end of the combustion chamber and propagates to the other. Diesel engines compress the vapor to a much higher ratio—say, 25:1—so that it combusts spontaneously, beginning at the edges and propagating inward.

The Mercedes design gets the best of both worlds by exploiting a formerly wasted product: the exhaust gas left over from the previous combustion cycle. That gas prewarms the incoming fuel-air mixture so that it needs less compression to reach ignition temperature. There are two such injections per cycle, and both require a very fine control of temperature and pressure.

When the piston reaches the top of its compression stroke, at a ratio closer to a spark-ignition engine's than a diesel's, the ignition begins spontaneously, not only at the edges of the chamber but at many points throughout. The result is a complete, efficient burn at temperatures too low for the formation of nitrous oxides—the diesel engine's Achilles' heel. Although the new engine's combustion produces less torque than you'd get from either a diesel or a spark-ignition engine, you'll never notice the lack under partial load—when you're at cruising speed, for instance. When you do need that torque, the engine operates just like its spark-ignition counterpart.

This design is known in the industry as homogeneous charge-compression ignition (HCCI), although Mercedes calls it DiesOtto, in homage to Rudolph Diesel and Nikolaus Otto, who invented the diesel and spark-ignition engines, respectively, in the 19th century. For many years the idea was shelved because practical engine controls were lacking. Relentless improvement in processing power, as quantified by Moore's Law, has now solved that problem.

The F700's engine includes two turbos—a small one for lower engine speeds, a large one for higher speeds—plus additional torque on launch from an electric motor integrated into the transmission. There's also a modification to the crankshaft, which the manufacturer doesn't spell out, that makes it possible to vary the engine's compression ratio. (Other manufacturers experimenting with HCCI engines, notably General Motors, make no such modification.)

The results are fairly startling. The carmaker claims 190 kilowatts (255 horsepower) at maximum load from a mere 1.8-liter four-cylinder engine while using only 5.3 liters per 100 kilometers (44 miles per gallon) at cruising speeds—in a vehicle weighing 1700 kilograms (3748 pounds).

The drawbacks? First, each cylinder needs its own pressure transducer so that the engine controller can fine-tune the combustion cycle, and those transducers are still very expensive. Second, the torrent of data from those transducers and other sensors makes the logic in the engine controller far more challenging.

CONCEPT

with integrated electric motor assist
company's name for the engine design)

In time, HCCI engines might be cheaper than diesels to build because they don't need the structural reinforcement that makes high-compression diesels heavier than conventional engines of equal power. They can also dispense with the complex emissions-control systems (such as Mercedes's Bluetec) that diesels need in order to meet California standards.

The F700 concept has a slew of other fascinating features, from rear-hinged rear doors to its Pre-Scan hydraulic active suspension, which continuously processes optical data from the road ahead to change its settings proactively.

The industry expects HCCI engines to make it into production sometime between 2015 and 2020. This concept car could be the basis of perhaps the least conservative model ever seen in the S-Class, the most prestigious Mercedes line. Even in a world of rising oil prices and legislated limits on carbon emissions, this daring vehicle shows that there's life left in the combustion engine. ❏

2009 BMW X6

PRODUCTION CAR

■ **POWER PLANT:** 298-kW (400 hp) 4.4-L twin-turbocharged direct-injection V8
■ **TRANSMISSION:** 6-speed automatic; steering wheel–mounted paddle shifters
■ **CLAIMED FUEL EFFICIENCY:** Information not available ■ **CLAIMED CO_2 EMISSIONS:** Information not available ■ **MORE:** The X6 lineup is likely to include both hybrid-electric and 197-kW 3.0-L six-cylinder diesel variants in the near future; the BMW X5 sport utility, to which it is closely related, will offer that diesel in 2009.

MEET FLEXRAY, THE NEW HIGH-SPEED AUTOMOTIVE DATA BUS

Remember how magical the first antilock brakes seemed, back in the 1980s, when they stopped your car smoothly with half the wheels on ice and the other half on dry pavement? Those systems processed sensor data a few times per second, feeding the information to a dedicated brake controller. Compare that with today's cars, which process data from scores of in-car sensors—and even include external factors, like vehicle proximity—and instantly crunch the numbers with up to a dozen control systems, integrated by a vehicle controller. Now consider tomorrow's car, which will be nothing less than a local area network on wheels. For it, the relevant metric will be bandwidth.

The BMW X6 is the first production vehicle to build in the next order of bandwidth, using a scheme called FlexRay, a high-speed data bus developed by a consortium of carmakers and component suppliers. FlexRay offers two communication channels, each with a data rate of 10 megabits per second, a 10- to 40-fold increase over current in-car communications protocols, depending on how the system is implemented.

FlexRay ferries data among the components of adaptive drive, a vastly enhanced descendant of yesteryear's automatic braking. Instead of just detecting a wheel's traction, adaptive drive uses a central controller to interpret sensor data on speed, steering angle, longitudinal and lateral acceleration, body and wheel velocity, damper position, and other criteria. The system controls body roll and adjusts the dampers to keep the vehicle stable during virtually any maneuver.

The all-wheel-drive X6—which BMW calls a sports activity coupe—doesn't stint on horsepower, either. It's offered with a 4.4-liter aluminum V8 that puts its twin turbochargers in a novel position. They nestle between the V-shaped banks of the engine instead of hanging off the exhaust manifolds outside the V. The scheme works because BMW has switched the position of the manifolds and the air intakes, so that the exhaust gases flow inside the V-formation and therefore need to travel just a few centimeters to reach the vanes of the charger's turbine. This way, the exhaust can spin the turbine up with less delay between stamping on the accelerator and getting that extra turbo goodness.

To make that process possible, the company developed turbochargers from materials that could operate in the hotter environment between the banks, a virtual oven that continuously bakes the turbo system at hundreds of degrees.

Another innovation is what BMW calls Dynamic Performance Control, or DPC—one entry in an alphabet soup of electronic traction, suspension, and engine control systems. The DPC controls the effects of a rear differential that includes two planetary gear sets, each containing a central gear (the "sun") spun by engine torque. This sun is surrounded by planet gears that are in turn housed in a ring gear that drives the individual wheel through two clutch packs, allowing the controller to reduce or multiply torque to each rear wheel individually to enhance steering, stability, and traction. ❏

2009 NISSAN GT-R

PRODUCTION CAR

■ **POWER PLANT:** 358-kW (480 hp) 3.8-L twin-turbocharged V6 ■ **TRANSMISSION:** Rear transaxle with sequential 6-speed; paddle shift ■ **CLAIMED FUEL EFFICIENCY:** Information not available ■ **CLAIMED CO_2 EMISSIONS:** Information not available ■ **MORE:** It took the company months to decide if the US $70 000 car would be released as a Nissan or an Infiniti in the United States; in the end, it stuck with the global Nissan brand despite Infiniti's upscale image.

POSSIBLY THE WORLD'S MOST PRACTICAL ULTRAHIGH-PERFORMANCE CAR

The Nissan GT-R has always combined pulse-quickening performance with technological innovation. It offered all-wheel drive, four-wheel steering, and twin turbochargers many years before these features could be had in lesser vehicles. This, the fifth generation since the GT-R's inception in 1969, is the first to be offered globally, including in the very visible U.S. market.

The car's designers have always eschewed the V8 or V12 engines used in many of its two-seater rivals, instead using twin turbochargers to squeeze out all the power it needs from six cylinders. This year, though, they're set in "V" formation, a switch from the prior model's in-line six. The resulting 358 kilowatts (480 horsepower) of power and 583 newton meters (437 foot-pounds) of torque are even more impressive, considering that the car also qualifies for the ultralow-emissions vehicle rating of the U.S. Environmental Protection Agency.

The engine sits aft of the front-wheel centers, and it drives not a conventional attached gearbox but a rear transaxle containing a dual-clutch transmission and transfer case, which then splits power among the four wheels. The dual-clutch transmission assigns separate clutches for the odd and even gears, letting it preselect the next highest and lowest gear for almost instantaneous shifts.

That unusual arrangement lets Nissan achieve a weight distribution of 53 percent front, 47 percent rear—close to the 50-50 ideal. The all-wheel drive system offers a torque split ranging smoothly from 100 percent rear to 50/50 front-rear. The driver can choose among three settings—Normal, Comfort, or R, for ultimate handling—for several systems, including engine and transmission mappings and suspension control. How often a GT-R driver would select Comfort is moot.

Nissan says the instrument panel display is "video game–inspired," not an unalloyed gain for those who prefer drivers to focus on driving. As is fitting in a performance car, the panel shows acceleration, brake-pedal pressure, and steering angle; it even records large blocks of operating data, like the black box on a jetliner. When not showing such data, the panel also controls the navigation system, audio equipment, and mobile phone system. ❑

2008 MAZDA2/MAZDA DEMIO

PRODUCTION CAR

NEWER, BETTER EQUIPPED... AND LIGHTER

The latest Mazda2 (called the Demio in some markets) has gotten more capacious, more capable, better equipped, and at 990 kilograms, 100 kg lighter—all at the same time. With one model that offers both Mazda's Miller-cycle engine, this time in 1.3-liter form, and the company's first continuously variable transmission, it begins to look like a very advanced small car indeed.

The Miller cycle increases the efficiency of a four-cycle "Otto" engine with a fifth cycle, by dividing the compression stroke into two parts. In the first 20 to 30 percent of the stroke, the intake valves are

■ **POWER PLANT:** 66-kW (89 hp) 1.3-L Miller-cycle 16-valve four-cylinder ■ **TRANSMISSION:** Continuously variable transmission (CVT) ■ **CLAIMED FUEL EFFICIENCY:** 4.3 L/100 km (55 mpg) on Japanese combined cycle ■ **CLAIMED CO_2 EMISSIONS:** 129 g/km ■ **MORE:** The "platform" or understructure will be the basis for a new Ford Fiesta in Europe, and Ford is considering selling it in the United States.

2009 JAGUAR XF

PRODUCTION CAR

■ **POWER PLANT:** 224-kW (300 hp) 4.2-L V8; 313-kW (420 hp) supercharged 4.2-L V8 ■ **TRANSMISSION:** 6-speed automatic; shift-by-wire control and paddle shifters ■ **CLAIMED FUEL EFFICIENCY:** Information not available ■ **CLAIMED CO_2 EMISSIONS:** Information not available ■ **MORE:** The XF is built on the underpinnings of the retro-styled S-Type, but you'd never know it; the production car retains (most of) the panache of Jaguar's jaw-dropping C-XF concept.

A STUNNING STEREO, IN A BREATHTAKING DESIGN

It's a striking, elegant departure, the first Jaguar to break away from traditional styling cues in 40 years. It may be the most important car in Jaguar's history, the one that must prove there's a future for the storied marque after Ford sells it to Tata Motors, the Indian maker of the lowest-priced car in the world (see "2009 Tata Nano").

Of course, you wouldn't be reading this if the XF were mere eye candy—its tech credentials are solid too. The interior fittings emerge from hiding only when needed. When a driver gets in, the car senses the proximity of the electronic key card and its "start" button pulses red. Pressing the button causes the rotary gear selector to rise out of the console and into the driver's hand. On first demonstration, you can almost hear Q of the James Bond films saying, "Really, 007, just *once* I would like to get a car back in one piece!"

Similarly, passengers can't see the dashboard vents until they wave their hands toward them, whereupon sensors trigger motors that rotate the vents into place. Overhead lights and the glove-compartment lid operate the same way. The goal is to reduce cabin clutter and increase the sense of soothing calm for all occupants; soft phosphor blue "halo" lighting heightens the mood.

The wizards of Bowers & Wilkins, an audiophile favorite in Worthing, England, planned the acoustics of this high-speed concert hall. They worked alongside Jaguar's engineers, putting 14 custom-designed speakers in the optimal places. The larger speakers have distinctive yellow Kevlar cones, for better linear response and reduced distortion; the four tweeters carry aluminum transducer domes that cut the weight of the one moving part, extending treble response an octave above that of standard designs.

The 440-watt surround-sound system uses Dolby logic in the remote amplifier, with the de rigueur inputs for personal MP3 players and USB storage devices, of course, all controlled through the car's touch-screen display. The system continuously monitors interior noise, adjusting its equalization to compensate.

Not all the tech goes toward creature comforts. There's a system that uses radar to alert the driver to nearby vehicles he or she can't see. The optional adaptive cruise control—quickly becoming a must-have on luxury cars—keeps the car a safe distance behind the one that's just ahead. And Jaguar also offers an automatic speed limiter—handy for those already saddled with a few speeding tickets. ❑

held open so the piston can push some of the fuel-air mixture out the door, as it were. This leakage eases the load at a point when the piston's leverage is at its worst. Then the standard procedure is to push the mixture back in again using a supercharger—a compressor driven by the crankshaft—until the piston reaches a mechanically more advantageous position in which to finish the compression. Because this exploitation of mechanical advantage saves more energy than the supercharger consumes, overall efficiency improves.

Mazda, however, dispenses with the supercharger, instead minimizing the fuel-air leakage with variable valve timing and clever tweaks to the combustion chamber. The company has also minimized the lower power and torque of the Miller cycle. Compared with the conventional version of the same engine, power is down just 1 kilowatt and torque declines just slightly, to 120 from 124 newton meters (89 foot-pounds).

Mazda says the 1.3-L Miller-cycle model uses just 4.3 liters per 100 kilometers (55 miles per gallon) in the Japanese fuel-economy cycle and cuts emissions to 75 percent below the old limits that took effect in 2005. (It is also offered with a 1.5-L engine, and a 1.4-L diesel in Europe.) The Mazda2 is not sold in the United States.

Ford is a part owner of Mazda, and so the car's design is an early indicator of one element in Ford's "blueprint for sustainability" to improve energy efficiency: make it lighter. Mazda slimmed the car down even while meeting new crash-safety standards and adding hardware, including entertainment gear and navigation systems. It did that by using ultrahigh-strength tensile steel and stronger welds to reduce weight while improving rigidity. It also improved the coefficient of drag to 0.32, respectable for a car just 3.9 meters long but 1.5 meters high and 1.7 meters wide. ❑

2009 TATA NANO

PRODUCTION CAR

■ **POWER PLANT:** 24-kW (32 hp) 623-cc aluminum two-cylinder ■ **TRANSMISSION:** Continuously variable transmission (CVT) ■ **CLAIMED FUEL EFFICIENCY:** 4.7 L/100 km (50 mpg) ■ **CLAIMED CO_2 EMISSIONS:** 120 g/km ■ **MORE:** Tata plans to sell an upscale version in Europe, possibly for as little as one-third the price of the cheapest new car today. European makers are apprehensive.

RE-CREATING THE PEOPLE'S CAR

In January, some 100 years after Henry Ford launched his Model T—the first car expressly designed for people of modest means—Ratan Tata did it all over again. The chairman of India's Tata Motors drove a white Nano onto the stage at the Auto Expo in New Delhi, making good on the promise of a 1-lakh car (100 000 rupees, or about US $2500).

Like predecessor "people's cars" that put whole nations on wheels—the Model T, Germany's Volkswagen Beetle, France's Citroën 2CV, Italy's Fiat 500—it uses technology only where it's needed.

The basic model forgoes air-conditioning, power steering, central locking, electric windows, a radio, a passenger-side mirror, even sun visors and a second windshield wiper. Its 623-cubic-centimeter two-cylinder engine produces only 24 kilowatts (32 horsepower)—roughly the same as a midrange motorcycle in the United States—and uses just a single balancer shaft to reduce vibration. However, it does have multipoint fuel injection (rather than a less precise carburetor), its exhaust is cleaned by a catalytic converter, and it is said to meet current European emissions regulations. Top speed is quoted at roughly 100 kilometers per hour (62 miles per hour)—although one Indian auto executive was quoted as saying that the wheel bearings will wear out quickly above 75 km/h.

Breaking with classic economy-car design, the 3.1-meter-long Nano does not use a transverse front engine and front-wheel drive. Instead, the engine is at the rear and under the floor, saving Tata Motors the cost of fancy constant-velocity joints to drive wheels that must also steer. Paradoxically, this allowed structural engineers to create a deeper front crush zone. In a frontal collision, that zone deforms more progressively and transfers energy throughout the frame, without thrusting a large lump of metal into the laps of front-seat occupants.

The car has an all-steel structure and includes such safety features as controlled-crush zones, side-intrusion barriers in the doors, and seat belts—though not a single air bag. Tata says the car was designed to pass international crash tests. Its weight of roughly 510 kilograms (1124 pounds), though, means the 500-strong engineering team will have to have done its calculations very carefully to achieve that goal. In a collision between cars of varying weights, the lighter one almost always incurs more damage.

So far, few if any reporters have even sat in a Nano, let alone driven it. But Tata Motors has ambitious goals, saying it expects to build 250 000 Nanos at a West Bengal plant in the car's first year of production, and perhaps 1 million or more annually once the company begins marketing them in developing nations throughout Asia, Africa, and Latin America. Tata Motors recently announced that it would develop a car capable of meeting European emissions regulations and sell it in Europe within four years.

Unlike Henry Ford, Tata must contend with his car's environmental impact. Only 7 of every 1,000 Indians now own cars; if that percentage were to quadruple, say, it could increase air pollution and traffic jams horrendously. Rejendra Pachauri, chairman of the Intergovernmental Panel on Climate Change, in Geneva, has gone so far as to say that the Nano disturbs his sleep. At the unveiling, though, Ratan Tata said that Pachauri "need not have nightmares." He noted that not only did the Nano meet all current Indian emissions standards but that in many cases it might replace a two-stroke scooter, which has far worse emissions.

At half the cost of the Maruti 800, currently India's cheapest new car, the Nano offers millions—or shall we say billions?—the dream of personal mobility. If the company can deliver on its promises, Tata's Nano could merit inclusion in a Top 10 Car list for all time. ❑

2008 VOLKSWAGEN POLO BLUEMOTION

PRODUCTION CAR

EXTREME FUEL ECONOMY, THE OLD-FASHIONED WAY

Demonstrating that diesel engines really do save fuel and cut greenhouse-gas emissions, Volkswagen's fuel-economy champ burns just 3.8 liters per 100 kilometers (62 miles per gallon) and emits just 99 grams per kilometer of carbon dioxide. That's far below the maximum fleet average of 130 g/km that the European community proposes to implement in upcoming regulations.

As Volkswagen often points out, it's also less than the 104 g/km of CO_2 that the Toyota Prius hybrid-electric

■ **POWER PLANT:** 1.4-L 59-kW (80 hp) three-cylinder turbodiesel ■ **TRANSMISSION:** 5-speed manual ■ **CLAIMED FUEL EFFICIENCY:** 3.8 L/100 km (62 mpg) in mixed urban/highway use ■ **CLAIMED CO_2 EMISSIONS:** 99 g/km ■ **MORE:** The BlueMotion tag indicates the most fuel-efficient variation of each model Volkswagen sells.

PRODUCTION CAR

FORD TEAMS UP WITH MICROSOFT TO TAKE ON GM'S ONSTAR

This glass-roofed, full-size Lincoln sedan offers the latest release of Sync, Ford's entertainment and mobile communications system, and it will also pioneer a brand-new fuel-efficient engine technology.

Codeveloped by Microsoft and Ford (which has a North American exclusive until the end of 2008), the current version of Sync coordinates entertainment, navigation, and mobile phone systems using voice-activated commands in English, Spanish, and French. Its Bluetooth wireless connection is said to work with virtually any Bluetooth phone and includes the transfer of ringtones and phone-book contents. Sync will thus play the ringtone associated with a specific caller, which can be heard through the car's speakers. Web-equipped phones can even stream audio to the sound system.

Sync's USB 2.0 port lets MP3 players and other devices recharge themselves and transfer files to a built-in hard drive, as well as a standard audio input jack. It reads aloud incoming text messages and e-mail, although it can't convert spoken responses back to text. Users can control the system by speaking to it, which lets them make calls without touching the phone—crucial wherever it's against the law to use handheld devices while driving.

Ford says the second release of Sync, due out this summer, will offer a host of new information within its navigation system as a separate option. The Sirius Travel Link subscription service will provide real-time news on traffic conditions in 78 U.S. markets as well as five-day weather updates, local fuel prices, movie listings, and other data via satellite download.

POWER PLANT: 2010 model: 254-kW (340 hp) 3.5-L turbocharged gasoline-direct-injection V6 **TRANSMISSION:** 6-speed automatic **CLAIMED FUEL EFFICIENCY:** Information not available **CLAIMED CO_2 EMISSIONS:** Information not available **MORE:** The EcoBoost engine was originally christened TwinForce, but Ford renamed it to play up fuel savings and lower emissions, moving away from a high-performance image.

Another feature, known as 911 Assist, puts Sync into direct competition with General Motors' OnStar system. It automatically has the driver's cellphone dial a 911 emergency service dispatcher whenever the vehicle's air bags deploy, unless the driver cancels the call in 10 seconds. Sync will be available on almost all Ford models by the end of this year. More than 1 million Sync-equipped cars are expected to be on the road next year.

Within a year of its launch this summer, the MKS will acquire its second innovation: Ford's EcoBoost engine, in 3.5-liter V6 form. Combining gasoline direct injection with a turbocharger, the V6 delivers power and torque at least equivalent to the company's 4.6-L V8, which breathes without any such respiratory assistance. Because it's so much smaller, though, it will realize a 10 to 20 percent improvement in fuel efficiency, and it will emit up to 15 percent less carbon dioxide.

Injecting the gasoline directly into the cylinder produces a cooler, denser charge, delivering better performance than conventional port injection, where the fuel is injected into air in the intake manifold. Adding a turbocharger specifically tuned for direct injection gives higher torque—460 newton meters (339 foot-pounds) versus 365 to 420 Nm for the V8—across a broad range of engine speeds. That delivers power when it's needed with fewer gear changes.

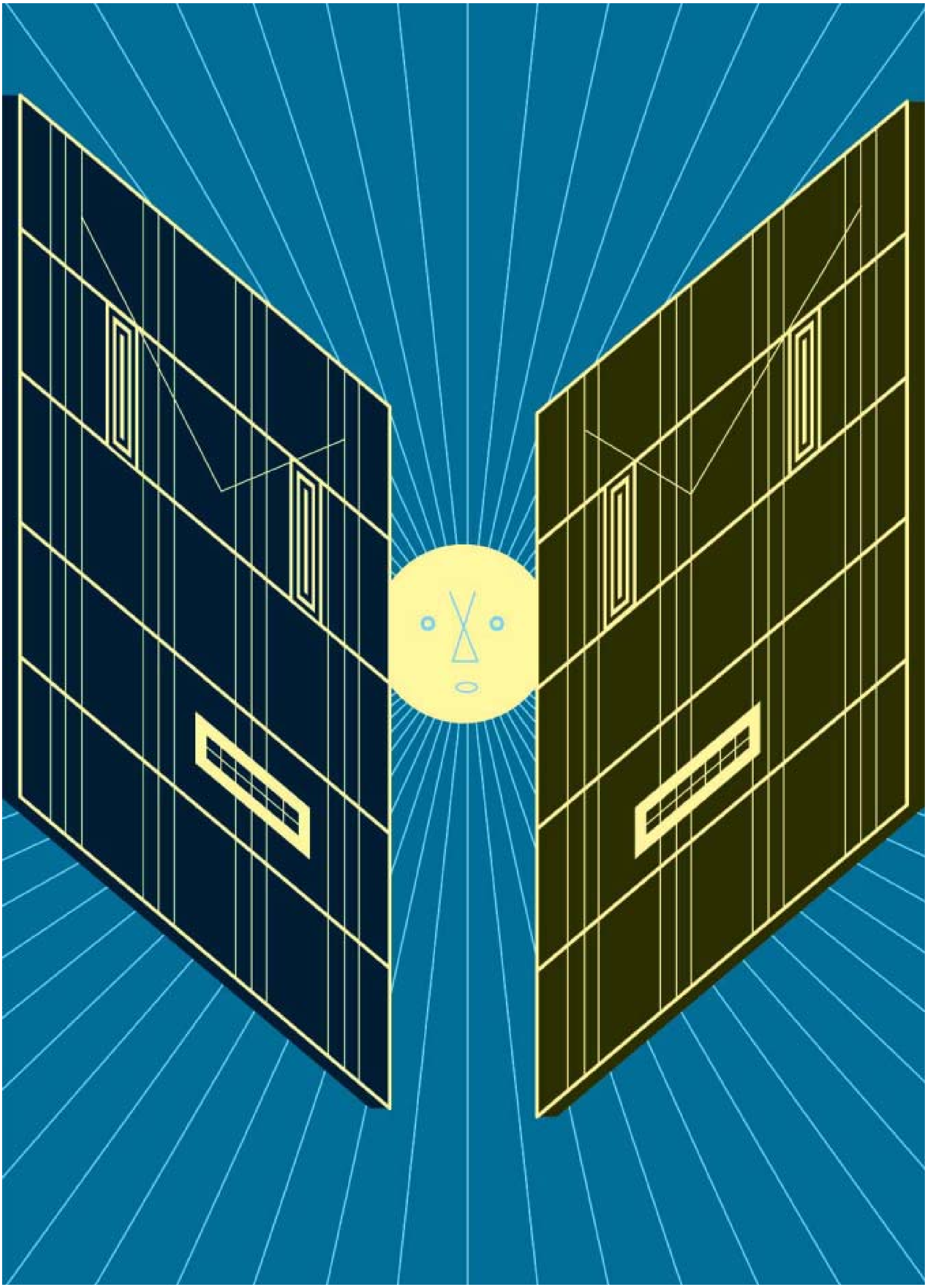
Ford is far from being the first carmaker to use direct injection and turbos, but this is the first time such an engine has been offered in volume to U.S. family-car buyers. The company has aggressive plans to roll out EcoBoost on both four- and six-cylinder designs, and it expects to be building half a million such engines within five years. ❑

vehicle produces. The comparison's a bit unfair, because the Prius is the larger car, but it underscores just how much can be wrung from a turbocharged diesel in a car weighing less than 1100 kilograms (2425 pounds).

Starting with its standard 1.4-liter three-cylinder diesel engine, Volkswagen altered the direct injection mapping that squirts the fuel into each cylinder. It also took advantage of the variable geometry of its turbocharger—an exhaust-driven turbine that crams air into the combustion chamber. At low engine speeds, the turbo output passes through a smaller port to provide higher pressure until the engine revs up to full speed, when the port enlarges to keep the turbo's boost consistent.

It's worth noting that the Polo would not comply with North American emissions standards in its current form, even though it's fitted with a diesel particulate filter. But the 59-kilowatt diesel's high torque of 195 newton meters (144 foot-pounds) and top speed of 176 km/h (109 mph) make the Polo usable in all kinds of traffic. The gearbox uses higher ratios than other Polos, to reduce engine speed at a given road speed. And Volkswagen fitted unique front body panels—grille and front fascia—to lower the car's wind resistance at speed.

The first Polo BlueMotion, launched in the summer of 2006, consumed 3.9 L/100 km (60 mpg) and emitted 102 g/km of CO_2. For the 2008 model year, VW added tires with low rolling resistance and a number of further aerodynamic tweaks. The modifications brought the coefficient of drag down to 0.30—a challenge on such a small, square car—and improved on both of those numbers. And not a single advanced battery pack or electric-drive motor was needed. (Hedging its bets, VW showed a Golf concept with a diesel engine and full hybrid system at the March Geneva Motor Show that it said used a mere 3.4 L/100 km, or 69 mpg.) ❑



GREG MABLY

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Solar-Cell Squabble

Organic photovoltaics could be dirt cheap, but their efficiency is in dispute *By Peter Fairley*

For a while, 2007 looked to be the year when organic photovoltaic (PV) technology would finally come into its own. Reports from leading research labs claimed record-setting breakthroughs in performance. Meanwhile, the U.S. Department of Energy (DOE) began welcoming investigators working on organic PV to compete for its mainstream solar-research grants, and venture capitalists invested tens of millions of dollars in organic PV development firms like Konarka Technologies, in Lowell, Mass., and Plextronics, in Pittsburgh.

Spurring all this interest was the promise of a much cheaper and more versatile source of solar power. Unlike traditional semiconductors such as silicon, this newer class of PV employs carbon-based plastics, dyes, and nanostructures and can be manufactured via a printing process that would be far cheaper than the high-temperature vacuum processing used for inorganics. Organic PV is also much more flexible and lighter in weight than inorganics, suggesting an enormous range of uses, including portable battery chargers and power-producing coatings for roofing shingles, tents, and vehicles.

Of course, such promising possibilities will only materialize once the technology becomes robust and powerful enough to be commercialized. That, too, seemed increasingly likely last year. In April, scientists from Wake Forest University, in Winston-Salem, N.C., announced a cell with a 6.1 percent energy-conversion efficiency—meaning that the cell captured as electricity 6.1 percent of the photon energy hitting it. The Wake Forest device represented a huge step up from a 4.8 percent efficient cell made by Konarka, until then considered organic PV's best in show. Three months later, Alan Heeger, the Nobel Prize–winning researcher at the University of California, Santa Barbara, who had pioneered organic electronics, trumpeted a device having a 6.5 percent efficiency.

What made those announcements so significant was that the numbers were just shy of the 7 percent mark that some developers peg as the threshold for successfully marketing organic PV for rooftop applications. While commercial inorganic PV panels now boast 10 to 20 percent efficiencies, organic PV developers are betting on finding markets at much lower performance levels, thanks to the technology's lower manufacturing cost.

But even as the news of higher efficiencies emerged, some researchers were raising doubts. They noted that the cells had not been rigorously verified by independent testing labs, unlike Konarka's 4.8 percent cell and a 5.4 percent cell announced in August by Plextronics. In November, 21 organic PV researchers in the United States and Europe published an editorial in the journal *Materials Today* bemoaning the "significant number" of organic cells that had recently been reported with "unrealistic and scientifically questionable" performance.

IN DISPUTE: David Carroll [right] of Wake Forest University, led a team that last year reported having developed an organic solar cell with a record-setting 6.1 percent energy-conversion efficiency. Such technology could eventually be used to make power-generating coatings for cars, tents, and roof shingles. But some solar-cell experts, including Keith Emery of the National Renewable Energy Laboratory [left], contend that Carroll and other organic PV researchers are sidestepping proper verification of their devices.
PHOTOS: LEFT: NATIONAL RENEWABLE ENERGY LABORATORY; RIGHT: KEN BENNETT/WAKE FOREST UNIVERSITY

The signatories included Keith Emery, director of the PV certification lab at the DOE's National Renewable Energy Laboratory (NREL) in Golden, Colo. [see photo, "In Dispute"]. Disagreements over solar-cell efficiencies aren't new, but in the past Emery had preferred a low-profile approach to resolving competing claims. Not this time. He says he felt compelled to raise the alarm over what he viewed as widespread disregard for standard test methods. "Some members of the organic PV community seem to have not followed the knowledge gained by...other mainstream PV technologies," Emery says. "They haven't read the literature."

Emery and others working with PV fret that a reputation for bogus reporting could erode the field's legitimacy and scare off investors. "Truth in advertising is critical," says University of Denver physicist Sean Shaheen, who contributed to an early organic PV cell in 2000 that kick-started today's race to market. "The concern is that somebody starts investing money on a false claim and loses a lot of money, and therefore confidence in the field is shattered."

YOU MIGHT THINK that measuring a solar cell's efficiency is simply a matter of shining sunlight on it and recording how much electricity comes out. But it's more complicated than that.

For starters, testers tend not to use actual sunlight to measure efficiency, because the amount of light can vary from day to day and place to place. Instead, they replicate sunlight using an artificial light source that they carefully calibrate and characterize. The key variables are the intensity of the illumination and its color balance. The standard level of illumination is 100 milliwatts per square centimeter (or 1000 watts per square meter, which is roughly equal to full sunlight hitting the Earth's surface). This, along with a precise definition of the cell's area, controls how much raw energy the device receives during testing.

Getting the color balance right is more about measuring how wrong it is, because no light source has the same spectrum as sunlight. To start, the tester measures the deviation of the light source from a standard solar spectrum. Then, to understand how that deviation will affect the test cell, he or she determines the experimental cell's sensitivity to different hues of light—that is, its spectral response [see photos, "Up Close"]. The power output from the cell is measured one wavelength at a time, using monochromatic light generated by a spectrometer. Once the spectrum of the light source and the spectral response of the cell have been obtained, the tester can calculate what's called a spectral-mismatch factor, which expresses how much a given light source will under- or overestimate the cell's capacity to convert sunlight into electricity.

Power output is determined by exposing the cell to the calibrated light source and measuring the current produced as a function of the voltage on the circuit. The optimal combination of voltage and current—corrected for spectral mismatch—represents the cell's maximum power output. Divide by the energy of illumination the cell received and you've got the cell's conversion efficiency.

Although such standard verification procedures have long been used for inorganic PV, it's easy to introduce errors when applying them to organic solar cells. That's because the unconventional semiconductors that make organic technology so exciting are also tricky to manipulate and measure. Most of the organic PV being worked on today—and drawing the greatest interest from investors and researchers—are called bulk-heterojunction cells, which Heeger and his collaborators invented in the early 1990s. They are composed of conducting polymers and carbon nanostructures called buckyballs that, in the right combinations, mimic the light-absorbing *p-n* junction of inorganic photovoltaics. (Another type of organic PV technology known as dye-sensitized or Grätzel cells displays higher efficiencies in the lab but has limited commercial appeal because of its liquid components.)

Most experimental organic PV cells are produced by pouring a solution of polymers and buckyballs onto a glass plate, spinning the plate to spread the solution into a film, heating it to drive off the water, and then sandwiching the resulting film between electrodes. Under illumination, the conducting polymer absorbs photons, kicking off electrons that are then attracted by the buckyballs and routed to an electrode. To optimize the transfer of charges from plastic to buckyball—and thus the device's efficiency—researchers continually seek improvements in materials, heat treatments, and other processing tricks. Another tack is to stack PV cells on top of one another. Heeger's group created such an architecture for its claimed 6.5 percent efficient device.

Organic cells behave differently under illumination than their inorganic cousins. Organic cells absorb mostly short-wavelength light at the blue end of the spectrum, while inorganic cells—including the reference cells used to calibrate the test lamps—absorb mostly red and infrared light. That makes spectral mismatch more pronounced when testing organic PV, because the reference cell and experimental cell have widely divergent spectral responses.

At the same time, organic semiconductors are fragile, making it hard to get a precise fix on the spectral mismatch. To measure a cell's spectral response accurately can take hours and thousands of readings across the spectrum, during which oxygen- and moisture-sensitive semiconductors, coatings, and electrodes can degrade.

Finally, organic PV researchers tend to produce very small cells—some less than a millimeter on a side. The larger the cell, the greater the chance of its containing uneven layers of film, which degrades performance. But diminutive cells are more likely to exhibit what solar-cell experts call perimeter effects—extra illumination that creeps in from beyond the edges of the test cell, thereby exaggerating its performance. Certification labs will test any size cell (Emery says NREL has tested cells as small as 0.008 cm^2), but they give greater credence to cells that are 1 cm^2 or larger, a size that Emery says "is sort of the transition point where perimeter effects become less important."

Shaheen and Emery estimate that uncorrected spectral mismatch and extra illumination can exaggerate the conversion efficiency of test cells by as much as 50 percent. And their rapid degradation under testing conditions makes the organic PV a moving target. The perceived inattention to these measurement artifacts is what's fueling skepticism. "The community may think that there's 6 percent organic PV out there. I don't believe there is," Emery says.

IN A LETTER published in the December issue of *Applied Physics Letters*, Emery directly challenged the 6.1 percent efficiency claim from Wake Forest. The Wake Forest paper had described the group's use of temperature cycling to create polymer filaments in the bulk-heterojunction cells that enhanced their charge conduction and enabled thicker absorbing layers. The process purportedly boosted the cell's efficiency by nearly a fifth. Wake Forest's news release quoted project leader David Carroll, director of the university's nanotechnology center, as hoping to reach 10 percent efficiency in the coming year [see photo, "In Dispute"]. Emery's letter, however, argued that the true efficiency of Carroll's cell might be closer to 3 percent.

Emery's critique hinges on a mathematical cross-check that PV researchers rely on to spot weird results. It repurposes the measurements taken to map a cell's spectral response, using them to predict the current expected from the cell under sunlight. In essence, researchers multiply the values measured under monochromatic light by that wavelength's contribution to the solar spectrum and then sum them.

"THE CONCERN IS THAT SOMEBODY STARTS INVESTING MONEY ON A FALSE CLAIM AND LOSES A LOT OF MONEY, AND THEREFORE CONFIDENCE IN THE FIELD IS SHATTERED"

Carroll and his colleagues did not present that cross-check in their paper, so Emery used the spectral-response data provided and made the calculation himself. To square the resulting predicted currents with the 6.1 percent efficiency claimed, the cells would need to be generating more than one charged electron for each photon absorbed—a result that Emery dismisses as "not physically possible." Noting that Carroll accounted for spectral mismatch, Emery concludes that perimeter effects inflated the results. "The mistake is probably in the device area—which is not unexpected for a device with an area less than 10 mm^2," Emery wrote.

Carroll, however, stands by his results. He says Emery's cross-check is flawed because the spectral response presented in the paper is that of a related but nonidentical cell. Why present power measurements for one cell and spectral response for another? According to Carroll, the temperature cycling that produced the 6.1 percent cells also left them incapable of withstanding the spectral-response tests. "They came apart," he says.

Carroll charges that his critics' complaints are just the politically motivated sniping of scientific competitors. He expresses the utmost respect for Emery as a scientist, but Carroll also considers Emery to be the collaborator of a competitor who, like Carroll, is vying for grant money from the U.S. Air Force Office of Scientific Research, which underwrites much of the basic research in organic PV. "People are very aggressive," Carroll says, "and they're aggressive because of money."

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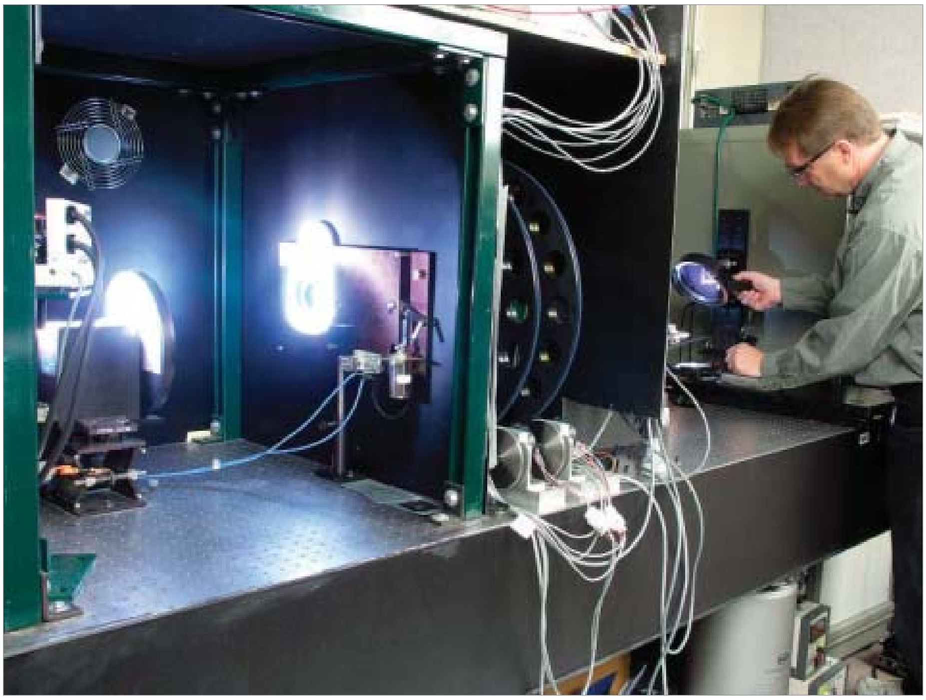

UP CLOSE: A technician [left] at the National Renewable Energy Laboratory measures the spectral response of a photovoltaic device, which indicates how sensitive it is to different hues of light. Industry leader Plextronics subjects its organic PV cells [right] to such independent evaluation, but others contend that the practice is expensive and time-consuming and that it stifles innovation.

PHOTOS: LEFT: NATIONAL RENEWABLE ENERGY LABORATORY; RIGHT: PLEXTRONICS

Emery insists that he simply calibrated test equipment for the researcher in question. "We had absolutely nothing to do with designing the cells," Emery says. "I won't let anyone in my lab get involved in fabricating PV technology." He adds that doing so would violate his lab's certification.

INORGANIC PV experts avoid such bickering through a culture of independent verification: prior to publishing, scientists and companies submit potentially record-breaking cells to international reference labs, including NREL, Germany's Fraunhofer Institute for Solar Energy Systems, and Japan's National Institute of Advanced Industrial Science and Technology, which offer such services at no cost to the researchers. The *Materials Today* editorial urged the organic PV community to adopt the same practice.

Easier said than done. The testing may be free, but preserving the fragile cells while they're en route and awaiting testing (a two- to eight-week queue at NREL) can cost several thousand dollars. At a minimum, the cells must be vacuum-packed. Better still is encapsulating the cells in glass or protective polymers—a sophisticated process that is beyond the expertise and resources of most academic labs.

Verification advocates recognize the added challenge but say that the interests of the community must prevail. "We have sympathy, up to a point," says Shawn Williams, vice president of technology for Plextronics, which does adhere to prepublication verification. Especially with the industry approaching commercialization, Williams says, record claims must be "tempered" with certified results: "It's about credibility. If people go out there and publish results that are not substantiated, then we or anyone else who's out there with real results get lost in the noise."

Some influential academics agree. One is Niyazi Serdar Sariciftci, a physicist at Austria's Johannes Kepler University Linz who collaborated with Heeger on his early PV research and whose work since then has helped Konarka raise more than US $100 million to commercialize organic PV. "In my opinion, every scientist has to go to an accredited lab and certify the claimed efficiency, particularly if the claim is for a world-record efficiency," Sariciftci says. "If it has never been reproduced objectively, it does not exist for science."

That kind of talk strikes others as elitist and counterproductive. "It took years to reproduce the Millikan oil-drop experiment. Therefore it didn't exist to scientists?" Carroll asks, referring to physicist Robert Millikan's famous 1910 experiment measuring the electron's charge and the resulting acrimonious debate that delayed Millikan's Nobel Prize by several years. Carroll says that a verify-then-publish system would thwart young researchers and other newcomers short on funds and influence. "That's going to begin to narrow down the number of people who are allowed to work and publish," he says. "Is that really what you want happening at a time when we need to be exploring all options in solar energy?"

Heeger echoes Carroll's last sentiment. He and others who favor the publish-first, verify-later approach could even point to one of Heeger's own early reports on organic PV technology: a 1995 paper in *Science* reporting a cell that, according to the authors, delivered a conversion efficiency of 2.9 percent, seemingly shattering the 1 percent ceiling that had defined organic PV for a decade. Competitors quickly recognized that a calculation error had more than doubled the reported power output. Despite the mistake, the paper continues to be heavily cited as a seminal advance that pointed a path to the organic PV devices now edging toward commercial readiness.

Heeger never issued a retraction and still makes no apologies for the error. "Numbers are indeed important," he says. "But scientific advances that demonstrate and enable quantum-step improvements are perhaps even more important." ❑

TO PROBE FURTHER The home page for the National Renewable Energy Laboratory's device-performance group (http://www.nrel.gov/pv/measurements/device_performance.html) has useful information about how it measures photovoltaic cells.

Materials Today*'s November editorial on organic PV testing, "The Value of Values," is available at http://dx.doi.org/10.1016/S1369-7021(07)70290-0.*

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TRAPPED ON TECHNOLOGY'S TRAILING EDGE

WE'RE PAYING TOO MUCH TO DEAL WITH OBSOLETE ELECTRONIC PARTS

BY PETER SANDBORN

Keeping aging systems on their feet is a daunting and resource-intensive task. The U.S. Air Force, for example, continually wages an internal battle to keep its weapons systems in fighting form. One enormous and often overlooked factor contributing to the early demise of military technologies is the problem of unavailable parts. Take the B-2 Spirit, a stealth bomber that first flew in 1989: by 1996, significant components of the aircraft's defensive management system, just one small part of its electronics, were obsolete. Repairing the system entailed either redesigning a few circuit boards and replacing other obsolete integrated circuits for US $21 million, as the B-2 program officers chose to do, or spending $54 million to have the original contractor replace the whole system. The electronics, in essence, were fine—they just couldn't easily be fixed if even the slightest thing went wrong.

Although mundane in its simplicity, the inevitable depletion of crucial components as systems age has sweeping, potentially life-threatening consequences. At the very least, the quest for an obsolete part can escalate into an unexpected, budget-busting expense. Electronics obsolescence—also known as DMSMS, for diminishing manufacturing sources and material

NOT GRANDMA'S ATTIC: An employee fills an order for a discontinued semiconductor product at a Rochester Electronics distribution center in Newburyport, Mass.

PHOTO: BOB O'CONNOR

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shortages—is a huge problem for designers who build systems that must last longer than the next cycle of technology. For instance, by the time the U.S. Navy began installing a new sonar system in surface ships in 2002, more than 70 percent of the system's electronic parts were no longer being made. And it's not just the military: commercial airplanes, communications systems, and amusement-park rides must all be designed around this problem, or the failure of one obsolete electronic part can easily balloon into a much larger system failure.

The crux is that semiconductor manufacturers mainly answer the needs of the consumer electronics industry, whose products are rarely supported for more than four years. Dell lists notebook computer models in its catalog for about 18 months. This dynamic hurts designers with long lead times on products with even longer field lives, introducing materials, components, and processes that are incompatible with older ones.

The defining characteristic of an obsolete system is that its design must be changed or updated merely to keep the system in use. Qinetiq Technology Extension Corp., in Norco, Calif., a company that provides obsolescence-related resources, estimates that approximately 3 percent of the global pool of electronic components becomes obsolete each month. PCNAlert, a commercial service that disseminates notices from manufacturers that are about to discontinue or alter a product, reports receiving about 50 discontinuance alerts a day. In my capacity as an associate professor of mechanical engineering at the University of Maryland, College Park, and a member of the university's Center for Advanced Life Cycle Engineering, I have been developing tools to forecast and resolve obsolescence problems. To deal with that growing pile of unavailable supplies, engineers in charge of long-lasting systems must basically predict the future—they must learn to plan well in advance, and more carefully than ever before, for the day their equipment will start to fail.

THE SYSTEMS HIT HARDEST by obsolescence are the ones that must perform nearly flawlessly. Technologies for mass transit, medicine, the military, air-traffic control, and power-grid management, to name a few, require long design and testing cycles, so they cannot go into operation soon after they are conceived. Because they are so costly, they can return the investment only if they are allowed to operate for a long time, often 20 years or more. Indeed, by 2020, the U.S. Air Force projects that the average age of its aircraft will exceed 30 years—although some of the electronics will no doubt have been replaced by then.

Some of the best examples of obsolescence come from the U.S. military, because it has been managing long-cycle technology programs longer than just about any other organization in the world. But there are also commercial aircraft that fall into the same, almost incredible age range of 40 to 90 years. The Boeing 737 was introduced in 1965 and the 747 in 1969; neither is expected to retire anytime soon.

When those systems were first built, the problem of obsolete electronics was only vaguely addressed, if at all, because the military still ruled the electronics market, and the integrated circuits they needed remained available for much longer than they do now. In the 1960s, the expected market availability for chips was between 20 and 25 years; now it's between two and five. Call it the dark side of Moore's Law, which states that the number of transistors on a chip doubles every 18 to 20 months: poor planning for parts obsolescence causes companies and militaries to spend progressively more to deal with the effects of aging systems—which leaves even less money for new investment, in effect creating a downward spiral of maintenance costs and delayed upgrades.

The situation is a lot like owning a car, which sooner or later begins to show its wear. First the brakes may need to be replaced, say, for $1000. Then it's the transmission—$2000. Pretty soon you start wishing you'd just bought a new car, except that the money you've sunk into maintaining the old car makes it likely that you won't be able to afford a new one.

The Defense Department spends an estimated $10 billion a year managing and mitigating electronic-part obsolescence. In some cases, obsolescence can trigger the premature overhaul of a system. The F-16 program, for example, spent $500 million to redesign an obsolete radar. In the commercial world, telecommunications companies spend lots of money managing obsolescence in infrastructure products, such as emergency-response telephone systems. One way to deal with it is to replace a failed device with a wholly redesigned one; another is to stockpile warehouses full of parts to cover the projected lifetime of a system. Both options cost money that might have otherwise been spent on expanding the business.

Obsolescence also isn't limited to hardware. Obsolete software can be just as problematic, and frequently the two go hand in hand. For example, an obsoles-

CALL IT THE DARK SIDE OF MOORE'S LAW: POOR PLANNING CAUSES COMPANIES TO SPEND PROGRESSIVELY MORE TO DEAL WITH AGING SYSTEMS

GRIZZLED VETERANS

MAJOR MILITARY SYSTEMS often last 40 to 90 years. During those lifetimes, models are updated and systems retrofitted. But many newer versions still use the same electronic subsystems as the originals. Shown here are the start of development and the projected end of support for each program.

B-52

94+ YEARS Start: 1946 Phaseout: 2040

AIM-9

72+ YEARS Start: 1953 Phaseout: 2025

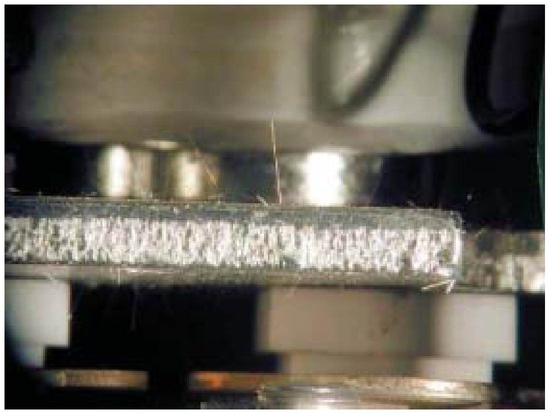
KC-135

63+ YEARS Start: 1954 Phaseout: 2017

FROM LEFT: U.S. AIR FORCE; BOB SIMONS/U.S. AIR FORCE; SUZANNE DAY/U.S. AIR FORCE cence analysis of a GPS radio for a U.S. Army helicopter found that a hardware change that required revising even a single line of code would result in a $2.5 million expense before the helicopter could be deemed safe for flight.

THERE IS A WAY out of the obsolescence mess, but first we need to understand how systems became so entangled in the first place. In the United States, electronic-part obsolescence began to emerge as a distinct problem in the 1980s, with the end of the Cold War. To save money and to open up the military to the more advanced components developed by the commercial world, the Pentagon began relying much less on custom-made "mil-spec" (short for military-specification) parts, which are held to more stringent performance requirements than commercial products. This policy, called acquisition reform, affected many nonmilitary applications as well, such as commercial avionics and oil-well drilling and some telecommunications products, which had historically depended on mil-spec parts because they were produced over long periods of time. Now at least 90 percent of the components in military communications systems are commercial off-the-shelf products, and even in weapons systems the figure comes to 20 percent, mostly in the network interface. The vast majority of the memory chips and processors in military systems come from commercial sources.

A European Union–driven ban on the use of lead in electronic components that took effect in July 2006 has exacerbated the situation. Although military, avionics, and most other long-lasting systems are actually exempt from the directive, those exemptions amount to little. Consumer electronics makers aiming their products at international markets comply with the ban—which in turn pushes the IC manufacturers to remove all lead from their parts. The main consequence of the ban is that traditional solder, which contained lead, had to be replaced with a lead-free alloy that was sufficiently cheap and also had the attractive mechanical, thermal, and electric properties of lead. Many such alloys, however, tend to sprout tiny "whiskers" over time, potentially causing short-circuiting. In 2005, for example, a nuclear reactor at the Millstone Power Station, in Connecticut, was shut down because some of its diodes had malfunctioned after forming whiskers, and in 2000 a $200 million Boeing satellite was declared a total loss after whiskers sprouted on a space-control processor. Both the unavailability of lead-based parts and the unreliability of some of their replacements are very real issues that plague longer-lasting systems.



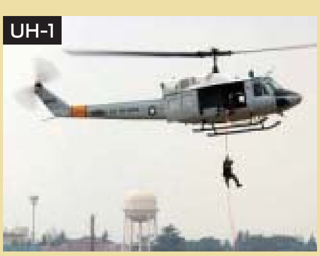
SNEAKY SPLINTERS: Tiny conductive whiskers grow within an electromagnetic relay. Systems can fail if whiskers cause short-circuiting or arcing. PHOTO: NASA ELECTRONIC PARTS AND PACKAGING PROGRAM

THE ABSENCE OF CRUCIAL PARTS now fuels a multibillion-dollar industry of obsolescence forecasting, reverse-engineering outfits, foundries, and unfortunately, a thriving market of counterfeits. Without advance planning, only the most expensive or risky options for dealing with obsolescence tend to remain open. The most straightforward solution—looking for a replacement part from a different manufacturer or finding it on eBay—faces substantial hurdles. For example, a part purchased from an unapproved vendor can involve costly and time-consuming "requalification" testing to determine that the replacement is entirely reliable and not counterfeit—a possibility that at the very least poses serious risks. [See "Bogus!," *IEEE Spectrum*, May 2006.]

Then there's the not-so-small matter of finding the right parts, which may exist in sufficient supply but be nearly impossible to track down. John Becker, former head of obsolescence planning for the Defense Department, tells me that the Federal Logistics Information System databases encode parts made by 3M in 64 different formats. That includes small differences in the way the company's name appears, like 3M versus 3 M or MMM, and so on. And that number doesn't even count the Air Force, Army, and Navy databases, nor all the ways that Lockheed Martin, Boeing, or other contractors might keep track of 3M's parts. A standardized method for encoding names and serial numbers would eliminate a lot of obsolescence cases by making it easier to track down the original parts, close substitutes, or upgraded versions.

For truly critical cases, procurement officers can turn to aftermarket manufacturers that are authorized by companies like Intel and Texas Instruments to resurrect their discontinued integrated circuits. An original manufacturer might give Lansdale Semiconductor or Rochester Electronics uncut wafers, which can later be finished on demand. Although reliable, this custom-assembly approach costs about $54 000 (in 2006 dollars) for a production run that might yield as few as

SOURCE: U.S. AIR FORCE



53+ YEARS Start: 1955 Phaseout: 2008

37+ YEARS Start: 1969 Phaseout: 2006

56+ YEARS Start: 1969 Phaseout: 2025

56+ YEARS Start: 1970 Phaseout: 2026

FROM LEFT: VAL GEMPIS/U.S. AIR FORCE; JUSTIN K. THOMAS/U.S. NAVY; U.S. AIR FORCE; U.S. NAVY

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50 units of one integrated circuit, according to a report by ARINC, an operations consulting firm. (Rochester disputes this figure, saying it can resurrect a TI wafer for between $5000 and $20 000.)

Another option is to redesign or reverse-engineer the part, but that could take 18 months. If the system in question is critical, a year and a half is simply too long. The ARINC analyses indicate that a redesign can run between $100 000 and $600 000, and even that may be conservative.

The most common plan—when a company or defense program has a plan—is to wait until a supplier announces the end of a product's manufacturing cycle and then place a final order, hoarding the extra parts the company expects it will need in order to support the product throughout its lifetime. But such lifetime purchases can turn out to be trickier than one might expect.

First, not all manufacturers send out their alerts enough in advance to allow their customers time to request a final factory run. The Government-Industry Data Exchange Program, or GIDEP, estimates that it receives about 50 to 75 percent of the obsolescence notices that are relevant to the Defense Department. That does not mean that all those alerts reach program managers before the product has been discontinued, despite the industry standard of 90 days' notice.

Second, it can be hard to know how many parts to stockpile. For inexpensive parts, lifetime buys are likely to be well in excess of forecasted demand, because a manufacturer may set a minimum purchase amount. Consider one major telecommunications company (which wishes to remain unnamed for competitive reasons) that typically buys enough parts to fulfill its anticipated lifetime needs every time a component becomes obsolete. Currently, the company holds an inventory of more than $100 million in obsolete electronics, some of which will not be used for a decade, if ever. In the meantime, parts can be lost, degrade with age, or get pilfered by another product group—all scenarios that routinely undermine even the best intentions of project managers.

THE ANSWER, THEN, involves more than removing bureaucratic hurdles. Better databases don't obviate the somewhat spontaneous, panic-driven responses that program managers can feel forced to make when they see that a part's production is about to cease. Ultimately, only a focus on strategies that try to predict the future can offer dramatic improvements to product managers facing component obsolescence.

Such companies as i2 Technologies, Qinetiq, Total Parts Plus, and PartMiner have produced commercial tools that forecast obsolescence by modeling a part's life cycle. To derive a forecast, the services weigh a product's technical attributes—for example, minimum feature size, logic family, number of gates, type of substrate, and type of process—to rank parts by their stages of maturity, from introduction through growth, maturity, decline, phase out, and obsolescence. At the Center for Advanced Life Cycle Engineering, my colleagues and I have added another dimension to the prediction, by mining commercial vendors' parts databases for specific market data, including peak sales years and last order dates.

Different factors drive the obsolescence of different electronic parts, and life-cycle modeling must be tailored to the type of part. Monolithic flash memory is one simple case: it turns out that successive generations of memory have fairly predictable peak sales years that correlate closely to an increase in size. By plotting this relationship, we see that one key attribute—the number of megabits—drives the obsolescence of monolithic flash memory. I analyzed historical data from different manufacturers to see when they required final orders for a given flash-memory product. (After a final order, a product is considered obsolete, even though it may still be available through aftermarket sources for some time.) To predict when a part type is likely to become obsolete, I used a manufacturer's last order dates, expressed as a number of standard deviations after the peak sales year, to make a histogram for different versions of the product. For each size of a particular Atmel flash-memory chip, it turned out that the last order dates, on average, came 0.88 standard deviations past the peak sales year.

For other components, however, the key attribute driving obsolescence may be less clear. Take the obsolescence of an opera-

TO THE BONEYARD: Eventually, obsolete subsystems overwhelm even the hardiest aircraft, dooming them to retirement in desert corrals. PHOTO: MATTHEW CLARK

SEED VAULT: Ten billion obsolete dies sit in a wafer bank at Rochester Electronics. PHOTO: BOB O'CONNOR tional amplifier. No single attribute drives its obsolescence, so I turned again to data mining and plotted 2400 data points from seven manufacturers to find the number of years a part could be procured from its original manufacturer. Operational amplifiers introduced in 1994 could be procured for eight years; in 2004, that availability had dropped to less than two years.

However, predicting when parts will become unavailable is still not enough information on which to build a business plan. A product manager also needs to know what to do once that date arrives. For this we turn to refresh planning. The goal of refresh planning is to find the best date to upgrade a product and to identify the system components on which the redesign should focus. I have developed one such methodology, called mitigation of obsolescence cost analysis, or MOCA, which determines when a design refresh should occur, what the new design should accomplish, and how to manage the parts that go obsolete before that time.

The software starts with a system's bill of materials. For each component—be it chips, circuit boards, or even software applications—we estimate the dates by which we expect them to become obsolete and the costs of procuring them before that time. Based on those estimates, MOCA determines a timeline of all possible design refresh dates, in which a design refresh is primarily intended to preserve, rather than improve, a system's functionality. (For many long-life systems, this is all a manager really wants.) The tool comes up with a set of possible design plans, starting with zero design refreshes—meaning that the best strategy is to be reactive, for example by finding substitute parts or reverse-engineering—up to and including the plan that entails a refresh for every component that is expected to go obsolete. MOCA takes into account uncertainty as well, by assigning probabilities to each projected obsolescence event.

The results are not easy to generalize and depend heavily on the peculiarities of each system, which underscores why planning around obsolescence can be so difficult. A MOCA study from 2000 on the engine controller for a regional jet, for example, found that the optimum solution entailed four design refreshes before 2006. Many other systems' analyses, however, have concluded that scheduling zero refreshes is the most cost-effective plan. This means, for example, that the ideal approach could be to merely stock up before a part ceases production to cover the lifetime of the system. Usually it's a combination of measures. The costs of requalification testing, buying, and storing spare parts and of performing the design refresh itself are all included in the tool's life-cycle analyses.

In 2003, we looked at a radar system in the F-22 Raptor. Using 1998 data, we projected that the optimal time for a design refresh would be in 2004. Northrop Grumman then did an independent analysis and drew the same conclusion. This was a good proof of concept for our predictive abilities: MOCA could predict six years in advance what later turned out to be the best course of action.

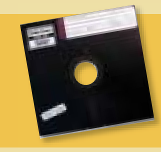
While it's nice to know ahead of time what you'll need to do in the future, this kind of analysis is also a money-saving measure. A study done in 2005 on a Motorola radio-frequency base station communications system identified a design refresh plan that would cost about one-fourth of what it would cost to stock up on each part that might go obsolete during the lifetime of the base station. Motorola builds and maintains more than 100 000 systems for longer than 20 years.

Traditionally, the company addressed obsolescence events as they occurred, deciding on a case-by-case basis whether to perform a design refresh or order a lifetime supply of parts. This system management technique was in essence a "death by a thousand cuts" scenario, whereby valuable resources were directed to fund a continuous stream of independent decisions on how to manage parts. The company should have been looking instead at each part in the context of the product as a whole. The analysis concluded that Motorola's best course of action would be to perform one design refresh in 2011 and buy sufficient parts to cover any obsolescence that occurs before then; doing no refreshes (and instead making only lifetime buys) would cost $33 million more. The key to a successful refresh schedule is deciding on it well in advance, so that a project's budget can include that expense before irreplaceable parts become a serious business liability.

Obsolescence problems—whether acknowledged or not—are a big part of the costs associated with electronically complex products in numerous sectors. For long-lasting systems, obsolescence is inevitable, but the spiraling costs that it can trigger are not. ❑

DEATH OF DIGITAL MEDIA

Jaz! Clik! Sparq! In no time, some of these storage devices leaped into oblivion. The media may survive, but will anyone be able to read them?

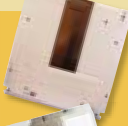


8" FLOPPY
Storage capacity: 100 KB–1 MB
Years in use: 1971–1981

5.25" FLOPPY
Storage capacity: 100 KB–1.2 MB
Years in use: 1976–mid-1980s

3.5" FLOPPY
Storage capacity: 400 KB–2.8 MB
Years in use: 1980–present

CD-ROM
Storage capacity: 650–900 MB
Years in use: 1982–present

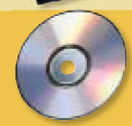


12" OPTICAL DISK
Storage capacity: 3.2–5 GB
Years in use: 1986–1992

5.25" OPTICAL DISK
Storage capacity: 650 MB
Years in use: 1988–1992

FLOPTICAL DISK
Storage capacity: 21 MB
Years in use: 1991–1993

ZIP DISK
Storage capacity: 100–750 MB
Years in use: 1995–present



DVD-ROM
Storage capacity: 4.7–17 GB
Years in use: 1996–present

SPARQ DISK CARTRIDGE
Storage capacity: 1 GB
Year in use: 1997–1998

JAZ DISK
Storage capacity: 1–2 GB
Years in use: 1998–2002

CLIK!
Storage capacity: 40 MB
Years in use: 1999–2001

SOURCES: ICPSR; SONY CORP.; DATALINK CORP.; IOMEGA CORP.; SILICONUSER; PCWORLD; UNIVERSITY OF SAN DIEGO

PHOTOS: ANNE R. KENNEY AND NANCY Y. MCGOVERN/CORNELL UNIVERSITY/ICPSR, UNIVERSITY OF MICHIGAN

Engineering the HARVARD ENGINEER

One man's determined quest to make Harvard a contender in engineering—after 372 years

By Erico Guizzo   Photography by Brad DeCecco

For most members of Harvard University's Faculty of Arts and Sciences, it was just another monthly meeting, the last of 2006. For Venkatesh Narayanamurti, dean of the Division of Engineering and Applied Sciences, it was one of the most important meetings of his career.

On that December afternoon, the professors gathered, as usual, at the Faculty Room, a spacious chamber in University Hall with sea-green and tan walls, lush Oriental carpets, leather-topped tables and chairs, five crystal chandeliers, and tall arched windows overlooking Harvard Yard. Dozens of oil paintings and marble busts of Harvard's past presidents and other luminaries—William James, Henry Wadsworth Longfellow, and Jean Louis Rodolphe Agassiz, to name a few—add to the aura of gravitas and tradition.

At 4 p.m., after the customary tea was served, Derek Bok, then Harvard's interim president, started the meeting. When it came time to discuss the docket items, Dean Narayanamurti stood up, glanced down at his notes, and then told his colleagues that, following a presentation on the topic he had made early that year, he was now ready to propose that the Division of Engineering and Applied Sciences be renamed the School of Engineering and Applied Sciences.

Despite the name change, the school would remain part of the Faculty of Arts and Sciences, the largest of Harvard's 10 faculty bodies, but it would now have the freedom to grow and establish collaborations across campus. This step, Narayanamurti told his colleagues, would "help to enable Harvard to meet the changing needs of the times and the challenges posed by the future."

As he concluded his remarks, he felt a wave of apprehension. The dean had spent the better part of the previous year working out all the details of such a move. Just a few months earlier, though, his well-laid plan appeared to be on the verge of collapse when then-president Lawrence H. Summers, who had come to accept the school upgrade, announced he would step down. Now, as the moment of judgment approached, Narayanamurti still had doubts about how some of his colleagues would respond.

RENAISSANCE ENGINEER: Venkatesh "Venky" Narayanamurti has led Harvard's expansion in engineering.

NANOSCIENCE, MEGABUILDING: Designed to foster collaboration in nanoscale research, the new 12 000-square-meter Laboratory for Integrated Science and Engineering connects eight buildings.

An instant of silence ensued, but no objections were raised; the motion passed by acclamation. The proposal would now go to the university's top governing body, the Harvard Corporation, to be ratified, and then Harvard would finally have the beginnings of what it had notably lacked for its entire 372-year history: a world-class engineering school on a par with the university's other famed dominions, such as business, law, and medicine.

As the meeting moved on to other business matters, Narayanamurti grinned from ear to ear.

SITTING IN HIS corner office in Pierce Hall last fall, Narayanamurti—known to nearly everyone as "Venky"—recounted that day and the chain of events leading up to it. Engineering at Harvard, he noted, has long been a modest enterprise in comparison with the university's world-famous humanities and social-sciences departments and professional schools. After World War II, when most elite U.S. universities nurtured their engineering schools into full-fledged enterprises, Harvard had lumped its engineering and applied-sciences faculty into one division. The division status didn't command much respect inside or outside Harvard, and even the engineering faculty joked that they spent more time explaining what the term *division* meant than what they did there.

The transition to school—the first new school at Harvard in 70 years—is designed to fill a glaring gap in Harvard's report card, Narayanamurti says. "Harvard will always get a grade of incomplete until it has a preeminent engineering school."

The expansion plan is certainly ambitious. Armed with the Harvard name and a US $999 million endowment, the engineering school plans to increase its faculty from 70 full-time professors to 100, double its graduate student body to 600, enhance undergraduate courses for nonengineering students, and establish more collaborations with other Harvard departments and with industry.

In pushing for a first-rate engineering presence at Harvard, Narayanamurti had the backing of some well-placed academics. Thomas E. Everhart, a former president of Caltech and a Harvard graduate who has presided over Harvard's board of overseers—a body that advises the university on a wide range of issues—says the move was long overdue. "With engineering and applied sciences becoming much more important in academia and in the economy as a whole, Harvard wasn't doing its share," he says. Since Narayanamurti became a dean at Harvard nearly 10 years ago, Everhart says, the technology-oriented fields are finally getting much more recognition.

Although Narayanamurti says his plan met with virtually no resistance on campus, people did raise lots of questions, the most obvious being: How would Harvard make a mark in engineering with the mighty Massachusetts Institute of Technology just down the street? And why would Harvard, essentially the world's greatest liberal arts college, want to do engineering anyway?

In countering those and other questions, the dean pointed out that engineering is essential to the kinds of interdisciplinary collaborations that drive today's cutting-edge research—collaborations that advance both basic and applied fields. He also argued that a modern liberal arts education needs to encompass technology too.

And as for "that small school down the road," as Narayanamurti jokingly refers to MIT, Harvard isn't interested in direct competition. Rather than cover the whole engineering universe, it plans to focus strategically on a few areas—nanotechnology, bioengineering, energy and the environment, computers and society—that, he says, "can leverage Harvard's strengths."

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At least one MIT luminary backs the Harvard plan. In a recent interview, Charles Vest, a former president of MIT and now president of the National Academy of Engineering, in Washington, D.C., noted that the timing couldn't be better, as the United States is under increasing pressure to train more engineers in the face of competition from Europe and China. "It's a great symbol to the country that a university that's been built largely around the liberal arts tradition is now saying, 'Look, technology is a big part of the world today, and it needs to be a part of us,' " Vest says.

IF HARVARD NOW appears ready to embrace engineering, it wasn't always so, says Frederick Abernathy, a professor of mechanical engineering and the engineering school's unofficial historian. Over the past century and a half, he says, engineering came close to disappearing from campus on several occasions.

The story begins in 1847, when Harvard started offering a formal technical curriculum under the auspices of the Lawrence Scientific School, named after Abbott Lawrence, a Massachusetts industrialist. The school had a promising start, but it would soon lose its edge to an upstart. In 1861, a geologist named William Barton Rogers, after failing to secure a faculty appointment at Harvard, founded another technical school: MIT.

The Lawrence school soon faced opposition from within Harvard Yard as well. Charles W. Eliot, perhaps Harvard's most influential president, felt that the applied sciences, with "a practical end constantly in view," was a poor fit with the university's liberal arts culture. During his tenure, Eliot—who, ironically, had taught analytic chemistry at MIT before becoming Harvard's president in 1869—did his best to eliminate engineering at Harvard or have it transferred to MIT.

In 1906, he succeeded in dismantling the Lawrence school, whose fragments were absorbed by other parts of Harvard. But his victory was short-lived, thanks to another Massachusetts industrialist, Gordon McKay, who made his fortune developing machinery for the shoe industry. Back in 1891, McKay had designated the Lawrence school as the chief beneficiary of his vast estate. He died in 1903, and six years later Harvard received the first $1 million of his bequest, to be used toward technical education and research.

Finally, in 1918, Harvard—after another failed attempt to combine its engineering efforts with MIT—decided to use the McKay money to reestablish its school of engineering. The school would not get hold of the entire bequest until 1949, as McKay's will provided lifetime payments to one of his two ex-wives, two sons, and several mistresses.

The McKay fortune went on to support 42 professorships, in effect keeping engineering alive at Harvard. But despite its accomplishments [see time line, "Yes, Harvard Has Engineering"], the overall engineering enterprise never attained world-class status. It never became, well, an MIT.

THINGS BEGAN to change in the mid-1990s, when Harvard president Neil Rudenstine and dean of the Faculty of Arts and Sciences Jeremy Knowles decided that basic scientific research at Harvard needed to be strengthened by more fully embracing engineering and technology. Knowles began consulting experts around the country on how to revitalize the engineering program, including what to look for in a new engineering dean. One of those experts was Narayanamurti.

One weekend in January 1998, Knowles flew to California to meet Narayanamurti, who was then dean of engineering at the University of California, Santa Barbara. "By the end of that Saturday morning," Knowles says, "I realized that I did not just want Venky's advice; I wanted Venky himself!"

Narayanamurti's career began in 1968, when, after receiving a Ph.D. in physics from Cornell University, he joined Bell Laboratories, where he would stay for 19 years. His Harvard office is festooned with memorabilia from the labs, where some of his underlings took to calling him Lord Venky because of his exacting style of management and his eye for spotting promising research.

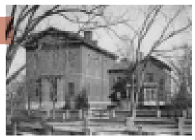
In 1987, Narayanamurti left Bell Labs and became vice president of research and exploratory technology at Sandia National Laboratories, in Albuquerque. Five years later, he moved on to Santa Barbara. There he expanded the faculty, fostered interdisciplinary programs, and established ties to the local high-tech business community. But the challenge of revamping Harvard engineering appealed to Narayanamurti, and in mid-1998 he moved to Cambridge.

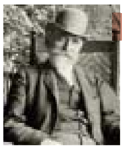
Over the next several years, he hired a dozen new faculty members—he stole at least three from MIT—to strengthen such areas as artificial intelligence, materials science, and biomechanics. The academic stars he recruited include Lene Vestergaard Hau, an applied physicist who devised experiments to slow and stop light pulses and then reconstitute them, and Federico Capasso, a former Bell Labs researcher and coinventor of the quantum cascade laser.

The expanded faculty, in turn, helped reinvigorate education in the division, especially at the graduate level. Under Narayanamurti's tenure, the graduate student body doubled to 350, with the number

YES, HARVARD HAS ENGINEERING

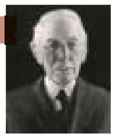
1847 Harvard creates the Lawrence Scientific School





1891 Gordon McKay designates Lawrence school the beneficiary of his fortune

1904 Harvard president Charles W. Eliot tries to merge the Lawrence school with MIT



1906 Lawrence Scientific School is dissolved

1918 Harvard reestablishes its engineering school

1919 George Washington Pierce invents a type of crystal oscillator that revolutionizes radio and telephony

1944 Howard Aiken develops the Mark I computer, and Grace Murray Hopper [right] becomes one of its first programmers

1948 Edward Purcell, Robert Pound, and Nicolaas Bloembergen pioneer nuclear magnetic resonance

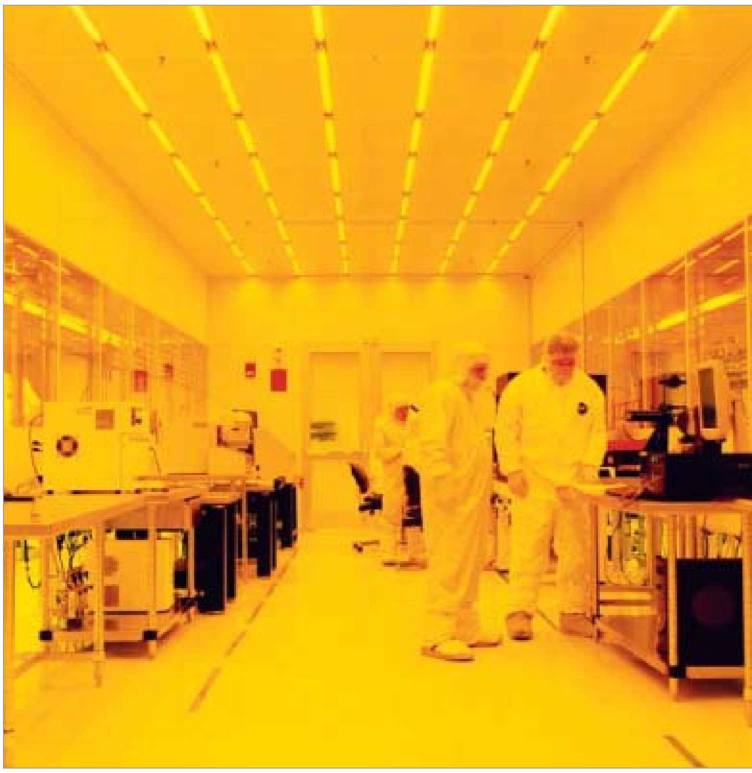
1949 Faculty of engineering and applied sciences lumped into a division

1975 Harvard dropout Bill Gates starts Microsoft; Steve Ballmer graduates in 1977 and joins the company in 1980

1999 Maxwell Dworkin building, built with donations by Gates and Ballmer, is dedicated

2007 The division becomes the School of Engineering and Applied Sciences

1975 PHOTO: JEFF CHRISTENSEN/GETTY IMAGES; ALL OTHER PHOTOS: HARVARD UNIVERSITY



UNDERGROUND RESEARCH: With two-thirds of its space below ground, the Laboratory for Integrated Science and Engineering building houses a 900-square-meter clean room and facilities for materials synthesis and advanced microscopy.

of applicants jumping nearly threefold, to more than 1200.

Narayanamurti's own profile accompanied that growth. On campus, he is said to know everybody and be known by everybody. His nickname is now so ubiquitous that he is quoted in the *Harvard Crimson* simply as Dean Venky. Ask about his personality and people say things like "builder," a "dynamo," a "bubbling enthusiast." "You walk into his office and you feel bombarded with ideas, and you come out feeling like you can take on the world," says Greg Morrisett, a professor of computer science. He said he came to Harvard in 2004 because he liked the direction Narayanamurti was taking. "I saw that this place was going to take off."

Despite all of Narayanamurti's efforts, though, the Harvard engineering program remains small compared with those of the top tech schools [see table, "Elite Engineering"]. Its faculty is about half the size of those of Princeton and Caltech, schools that Narayanamurti considers peers, and its research spending is a fraction of what big schools like MIT, Stanford, or Berkeley spend. In the latest *U.S. News & World Report* ranking of top U.S. engineering graduate programs, Harvard comes in at a disappointing 23.

After several years in the job, Narayanamurti says, he came to the conclusion that the division would become preeminent only if it drastically raised its profile. In particular, the idea of creating a first-rate engineering school had been around for a while. Narayanamurti's bosses, Rudenstine and Knowles, supported the idea, and so did a subcommittee of Harvard's board of overseers, which recommended the upgrade to school as early as 2002.

But when Narayanamurti began discussing the idea with Harvard president Larry Summers, Rudenstine's successor, the dean discovered that Summers was skeptical at first. The two men held several long, often heated conversations, and finally, by mid-2004, Summers came around to the idea.

With the support of the overseers and the president, it seemed as though Narayanamurti's plan was falling into place. He even found time to contemplate his retirement, and on 31 May 2005, he surprised his faculty with an e-mail announcing that he would step down the following year.

Then the Summers scandal broke. After making some controversial remarks on women in science, Summers became engulfed in criticism. A "lack of confidence" vote by the powerful Faculty of Arts and Sciences led to his eventual resignation in February 2006. For a while the venerable institution appeared leaderless, and nothing much seemed to get done.

Given the circumstances, Narayanamurti agreed to stay as dean until a new president was hired—and until the new engineering school was established. (Some at Harvard remember events slightly differently. One professor describes Narayanamurti's attitude as more like "Give me the school or else I won't stay.")

With Harvard's top echelon still in flux, Narayanamurti bolstered his efforts to rally his own faculty around the idea of an engineering school. "You'd pass Venky in the hall and he'd tell you about it," says Vahid Tarokh, a professor of electrical engineering. "Person by person, Venky—a one-man army—got everybody on board."

But convincing the rest of the Faculty of Arts and Sciences, which had the power to make or break the deal, proved a different matter. Some people, Narayanamurti says,

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feared that engineering could rapidly swell and begin siphoning money away from other disciplines. So Narayanamurti took to the paths of the Harvard campus and spent six months persuading colleagues in various departments and schools.

Theda Skocpol, a professor of government and sociology and former dean of the Graduate School of Arts and Sciences, says she found Narayanamurti's arguments credible. "We received assurances that, as in the past, [the engineering school's] faculty and undergraduate and graduate activities would remain closely tied with other parts of the university," Skocpol says. "This was understood as a welcome evolution rather than any kind of upheaval."

So when Narayanamurti put the motion before the Faculty of Arts and Sciences on 12 December 2006, he had done his homework. And after the unanimous vote passed, he was ecstatic. It also helps that Harvard's new president, Drew Gilpin Faust, is on board with the plan. In her speech at the school's launch last September, she credited Narayanamurti with maneuvering Harvard toward a more tech-friendly outlook, calling him "the North Star of our engineering galaxy."

After the Harvard Corporation ratified the engineering plan in February 2007, Narayanamurti created several committees to handle the transition from division to school, dealing with faculty growth, financial issues, collaboration with industry, and even the design for the school's seal. He continues to push for stronger cross-disciplinary collaborations, which he says are made easier by the fact that the school isn't divided into departments.

His vision of a school with few divisional barriers has helped attract new faculty. Capasso, who joined Harvard in 2003, recalls that he had entertained a number of offers from universities, but he "would not at first glance take Harvard very seriously. What changed my mind was that they were putting their money where their mouth was." In his case, the main attraction was the creation of the Center for Nanoscale Systems, which brought together several Harvard groups and is now based at the new Laboratory for Integrated Science and Engineering [see photos, "Nanoscience, Megabuilding" and "Underground Research"].

Susan Graham, a professor of computer science at the University of California, Berkeley, and a former president of the Harvard Board of Overseers who backed the upgrade to school status, notes that the open structure seems to prevent the usual departmental squabbling over resources. "The question now," she says, "is whether this will scale as they grow." As Narayanamurti continues to expand the faculty, he says he has been contemplating Graham's question. He says that once the faculty has about 100 full-time professors, the school will reach a "critical mass" to do significant things while remaining a manageable group.

He also wants to extend the school's interdisciplinary culture to the classroom. He asked his faculty to create new technology courses for students who are interested in, say, medicine or economics. At the same time, the engineering school is reviewing its curriculum to incorporate more hands-on learning.

Lynn Andrea Stein approves of the move. On sabbatical at Harvard, she is a professor of computer science and engineering at the Franklin W. Olin College of Engineering, in Needham, Mass., a new school that has gained attention for its innovative curriculum [see "The Olin Experiment," *IEEE Spectrum*, May 2006]. She adds, though, that Harvard shouldn't simply try to replicate Olin's ideas. "A lot of the questions that motivated the creation of Olin are also motivating changes at Harvard, and Harvard will have its own unique response," she says.

Narayanamurti sees the ideal graduate from his school as a renaissance engineer, one with a grounding in both technology and societal issues. "Those who want to be pure technologists should go to MIT," he says. "At Harvard we want to create people who know how things work but also how the world works."

Farther down Massachusetts Avenue, at MIT, people aren't completely oblivious to Harvard's expansion plans. It's just what MIT needs, one professor commented, "a sharp kick in the butt." Not so, predicted another: after a few years Harvard will just settle for being a very good but very small school of applied sciences, like those found at a lot of other liberal arts colleges.

Nobody at Harvard seems ready to concede just yet, and in fact, the school is already thinking about its long-term prospects. In January 2007, the university created a committee to advise Harvard's president and governing bodies on how to boost collaborative efforts in science and engineering. The committee, of which Narayanamurti is a member, should shape major expansion plans, including the Allston Initiative.

Having exhausted its land on the Cambridge side of the Charles, Harvard now intends to build a second campus in the Allston neighborhood of Boston. At press time, the university was set to begin construction on a $1 billion science complex. It's been suggested that the engineering school, in whole or in part, could move to Allston one day, but no concrete plans have been made. It's clear, however, that engineering and applied sciences will be a central part of the new development.

As for Narayanamurti, what's next? In mid-February, he announced he would step down as dean and return to teaching and research. And this time he means it. But he plans to stick around to see the changes he helped initiate. "It's going to be one of those things that you don't notice day to day," he says, "but when you come back in five years or so, it will be a tremendous change." ❑

With additional reporting by William Sweet in Cambridge, Mass.

ELITE ENGINEERING

How Harvard's new School of Engineering and Applied Sciences compares with other top U.S. engineering schools

ENGINEERING SCHOOLS	RESEARCH EXPENDITURES	FACULTY MEMBERS	GRADUATE ENROLLMENT
Massachusetts Institute of Technology	US $234.5 million	372	2662
Stanford University	$152.4 million	241	3243
University of California, Berkeley	$119.8 million	272	1639
California Institute of Technology	$80.9 million	131	601
Princeton University	$52.1 million	125	500
Harvard University	$35.2 million	73	345

SOURCE: Schools and *U.S. News & World Report*; graduate enrollment and research expenditures refer to 2006.

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JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY (JAIST) invites applications to an associate professor position at SCHOOL OF INFORMATION SCIENCE. The position is in a laboratory for information theory and signal processing. The appointment starts as soon as possible after September 1st, 2008.

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All applicants must submit the following items:
- A detailed CV and photograph,
- List of past research works, experienced projects, research funding received, and accomplishment,
- List of pedantic trainings and experiences the candidate has taken before,
- Publication list categorized as follows: international and domestic papers, reviewed international conference papers, books, patents, and other significant published contributions to the academic society, and
- Copies of the three most significant publications.

In a separate list, please also provide:
- Educational contributions and academic society activities such as editorship of book publications as well as international conference committee membership.
- Two references (names, organizations, and positions of references, and their e-mail addresses), and two recommendation letters,
- Summary of previous research work (maximum 1500 words), and goals-and-objectives, and plans towards the goals of future research work (maximum 1500 words), and
- Policy and role models of teaching/education (maximum 1500 words).

Deadline: Applications must be received by May 30, 2008

All applicants must send applications to:
Dean of School of Information Science,
Japan Advanced Institute of Science and Technology
School of Information Science

Attention to: Tadashi Matsumoto
1-1 Asahidai, Nomi-shi, Ishikawa, 923-1292, JAPAN
Tel: +81-761-51-1265, Fax: +81-761-51-1149

JAIST's School of Information Science is one of the largest and most advanced research and educational institutes of its kind in Japan. More information can be found at: *http://www.jaist.ac.jp/is/index.html*

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Candidates should have a PhD in electrical or electronics engineering, physics, mathematics or closely related fields, and have demonstrated the ability to conduct independent and successful research in their area of expertice, effective classroom teaching at graduate level, supervision of M.S., and PhD. students research leading to peer-review publications and develop and maintain external funded research programs. Interested candidates please submit your application and a letter stating research and teaching vision, a current resume and three Professional references to: CITEDI-IPN Search Committee Chair, Av. Del Parque #1310, Mesa de Otay Tijuana, Baja. California, Mexico CP 22510.

For information about CITEDI, and position refer to
http//www.citedi.mx
and lgonzal@citedi.mx.

Application will be accepted until positions are filled, women are specially encourage to apply.

Universität Karlsruhe (TH)
Forschungsuniversität · gegründet 1825
KIT Karlsruhe Institute of Technology

In the **Department of Electrical Engineering and Information Technology** at the University of Karlsruhe, Germany, the following position is to be filled:

W3-Professorship "Optical Communications"

Candidates should have an extensive experience in the fields of photonics and communications. An excellent scientific background and strong experience in heading research groups in a team-oriented environment is expected. A successful career over several years in industry or in industry-oriented research is advantageous. The candidate should be committed to excellence in teaching.
The position will be affiliated to **the Institute of High-Frequency and Quantum Electronics (IHQ)** at the University of Karlsruhe.

Candidates should be specifically experienced in several of the following areas:
- Optical Modulation Formats and Digital Signal Processing
- Optical Network Technology: 100 Gb/s Ethernet, Burst-Switched Networks, Fiber-to-the-Home (FTTH), Small Office & Home Office (SOHO) Networks, Optical Networks for Computer Clusters
- Optical Sensor Networks
- Quantum Cryptography, Secure Optical Networking
- Optical Interconnects
- Multiple Input – Multiple Output (MIMO)
- Integrated Optics, Nanophotonics, Free Space Optical Device Technology

In research we expect important initiatives in communications and optical technologies, especially in cooperation with established institutions and other similarly oriented research groups of the Department and the Karlsruhe Institute of Technology (KIT).

As for education we expect a dedicated participation in existing and new curricula of the Department, within the International Department and the Karlsruhe School of Optics and Photonics (KSOP).

The University of Karlsruhe is an affirmative action employer and applications from women and disabled are encouraged. German language knowledge or willingness to learn German is required.

Applications with the relevant documents have to be submitted by **July 4, 2008,** addressed to the **Dean of the Department of Electrical Engineering and Information Technology at the University of Karlsruhe, Kaiserstr. 12, D-76131 Karlsruhe, Germany.**

the data

BY PHILIP E. ROSS

Why CPU Frequency Stalled

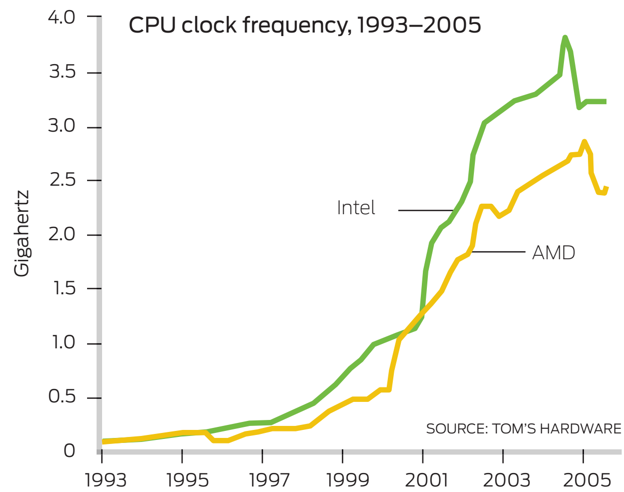
NOT SO long ago, competitive sorts would boast of the cycle rate of their PC's central processing unit. But now it seems the only people who talk it up are the overclockers—hobbyists who push their CPUs beyond their specified limits. There are two reasons: CPU clock rates peaked a few years ago [see graph, top], and they aren't a very useful key to chip performance anyway.

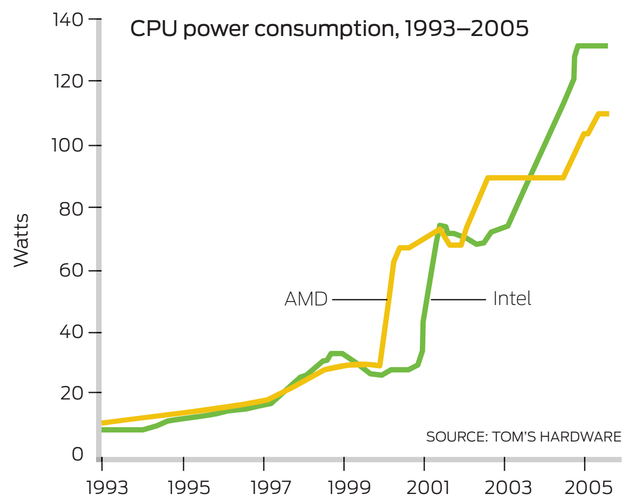
The clock keeps a processor's parts working in unison, like rowers on a galley ship. Other things being equal, the more ticks you have per second, the more work will get done.

So why not push the clock faster? Because it's no longer worth the cost in terms of power consumed and heat dissipated. Intel calls the speed/power tradeoff a "fundamental theorem of multicore processors"—and that's the reason it makes sense to use two or more processing areas, or cores, on a single chip.

Intel reports that *underclocking* a single core by 20 percent saves half the power while sacrificing just 13 percent of the performance. That means that if you divide the work between two cores running at an 80 percent clock rate, you get 73 percent better performance for the same power. And the heat is dissipated at two points rather than one. So even though the cutting-edge logic chip gulps ever more power [see graph, center], it isn't about to melt its way through the floor.

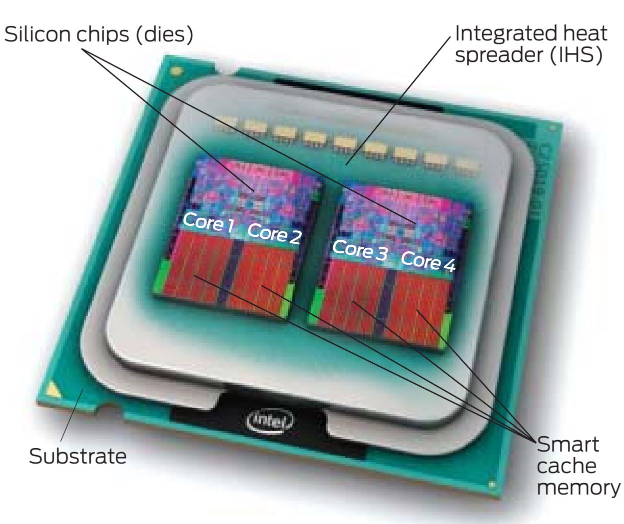
That bodes well for Moore's Law, which predicts that about every two years, manufacturers will double the number of transistors they cram onto a given bit of silicon. The fundamental theorem says that we'll still be able to make full use of those transistors for a good long time. If once the whole choir of transistors had to sing to the beat of a single metronome, now it can split up into sections—and harmonize. ❑

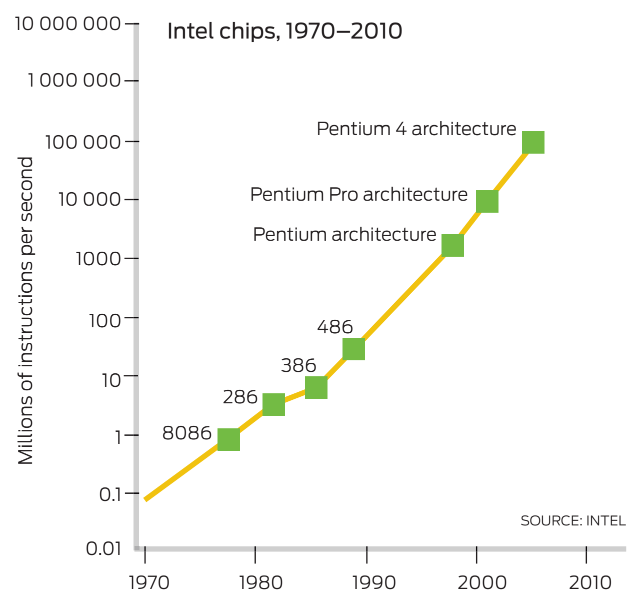




Count Paces? Or Measure The Distance Traveled?

The rising power consumption of CPUs [graph, center] made it less attractive to focus on cycles per second, so clock rates stalled [graph, top]. A better gauge of performance, the number of instructions performed per second [graph, bottom], continued to rise without betraying any hint of the stall. That's because work once done in a single processor is now divided among several processing cores—four of them in the case of Intel's Quad-Core chip [below].





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