THE MAGAZINE OF TECHNOLOGY INSIDERS

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05.08

GORDON MOORE LAYS DOWN THE LAW

REMEMBER ME FOR "ANYTHING BUT MOORE'S LAW," SAYS THE WINNER OF THE 2008 IEEE MEDAL OF HONOR

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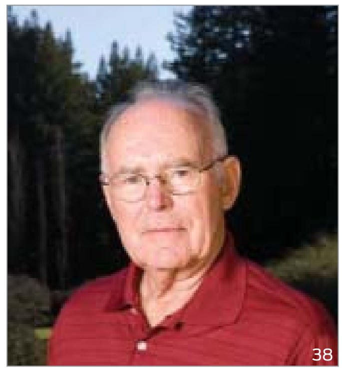

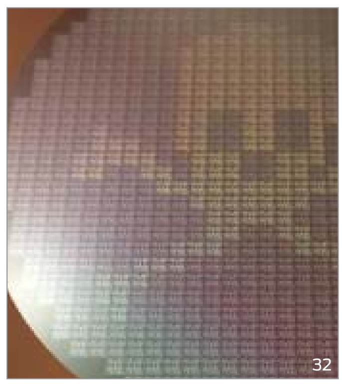

JONATHAN SAWYER is serious about going green; Gordon E. Moore gives an encore; what lurks inside military microchips.

COVER: JOSON

CLOCKWISE FROM LEFT: RAY NG; JOSON; JAMES ARCHER/ANATOMYBLUE

COVER STORY

UPDATE

OPINION

DEPARTMENTS

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

volume 45 number 5 international

ieee spectrum 05.08

YOU WOULDN'T know it by looking at them, but these Spykee robots are the modern descendants of the Erector set.

PHOTO: NIKKO AMERICA/MECCANO

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BUILD YOUR OWN ROBOT

Everywhere you look these days, people are building robots—which means there are more types of robot kits to choose from than ever before. But which one is right for you? Which one is right for your son or daughter? *IEEE Spectrum* blogger Mikell Taylor is a self-proclaimed robot geek, and she'll take you on a video tour through the sea of kits currently available, from the iPod-docking Spykee [above], to the VEX bots, which are optimized for educational competition.

ALSO ONLINE IN MAY:

ONE-ON-ONE WITH CLAYTON M. CHRISTENSEN: *IEEE Spectrum*'s editor, Susan Hassler, interviews the innovation guru to find out what the semiconductor industry can learn from the world's top car company.

SPY GADGETS "R" US: *IEEE Spectrum*'s Sally Adee sits down with Lisa Porter, the first director of the United States' new Intelligence Advanced Research Projects Agency.

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MEMBERS MAKING NEWS

Several IEEE members have garnered media attention recently for developing an antisliding adhesive that resembles a gecko's toe hairs, designing the first CMOS circuit that uses nanotubes, and developing a unit for genetic testing that's about the size of a shoebox.

PHOTO: KELLAR AUTUMN/LEWIS AND CLARK COLLEGE

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Two certification programs help test the skills of wireless communications engineers and midlevel software developers and engineers.

CONFERENCE COVERS NUCLEAR AND SPACE EFFECTS

Learn about the latest commercial, industrial, and medical applications for microelectronic devices and circuits used in radiation environments at the Nuclear and Space Radiation Effects Conference, to take place from 14 to 18 July in Tucson, Ariz.

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back story

JEAN KUMAGAI

Her First DARPATech

SALLY ADEE had barely taken off her coat after arriving for her first day of work at *IEEE Spectrum* last June when she began pleading to attend DARPATech, the Defense Advanced Research Projects Agency's convention. Her request was a little odd—most writers find obscure conferences they absolutely must attend in Honolulu, Paris, Tokyo, or maybe Vegas. Adee, a self-described defense nerd, really wanted to go to DARPATech—but never dreamed we'd actually send her.

We did. Two months later she found herself at the Anaheim Marriott in California, across the street from Disneyland, whose attractions compared poorly with the festivities at DARPATech as far as Adee was concerned. Among the 3000 defense contractors, academics, researchers, and DARPA program managers wandering the enormous hotel, Adee felt like she was at a whole different level of theme park. Instead of cotton candy, attendees carried Starbucks cups and DARPATech M&Ms tinted green, yellow, and a sickly, translucent white. The 2007 conference kicked off DARPA's 50th anniversary, and speakers were introduced with flashing lights and pounding rock music. Some of the music choices were puzzling—one program director jogged to the podium accompanied by a song that began "It's no surprise to me; I am my own worst enemy." The secretary of the Navy was introduced to the chords of the Violent Femmes' "Blister in the Sun."

Adee spent a lot of time hoarding swag—jealously guarding her stash of pixelated-camouflage T-shirts, light-up pens, temporary tattoos, and commemorative DARPA playing cards—and feeling a bit like Hester Prynne, wearing the scarlet badge that distinguished journalists from the defense contractors, who wore baby blue and duckling yellow tags. "I gained some insight into what it felt like to be a leper in the 1890s," she recalls, describing scientists and contractors halting conversations midsentence and turning away whenever she approached, dense crowds parting in her path. "Or maybe I'm thinking of Moses."

Inside the exhibit hall, the few reporters on-site could examine the latest and greatest bionic-arm prosthetics, watch robo-geckos climbing up vertical glass panes, and cheer on an autonomous learning robot called Little Dog that hobbled over treacherous rubble.

Sure, there were a few disappointments, like the 3-D glasses Adee is shown modeling above. When she tried them on, she was disheartened to find herself gazing at a PowerPoint presentation.

But even the best exhibits paled in comparison with the gossip floating around the conference. One especially juicy item led to Adee's story in this month's issue, "The Hunt for the Kill Switch." ❑

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. 5 (INT), May 2008, p. 7, or in *IEEE Spectrum*, Vol. 45, no. 5 (NA), May 2008, p. 11.

contributors

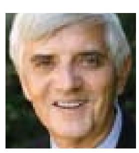
JAMES ARCHER's illustration opens "The Hunt for the Kill Switch" [p. 32]. He holds a bachelor's degree in both art history and biology and a master's in medical illustration. To create his digital illustrations and animations, he often uses 3-D applications and technologies. Archer teaches workshops for the Association of Medical Illustrators.

MARK ANDERSON, a self-described tech-savvy culture geek, profiled mashup masters Adrian & the Mysterious D [p. 18]. He traces his love of this pop-music phenomenon to the tape-splicing days of the 1980s. Anderson has written about both technology and music for such publications as *Wired* and *Rolling Stone*.

CLAYTON M. CHRISTENSEN is part of the multidisciplinary team that wrote this month's feature on applying Toyota's production methods to semiconductor manufacturing [p. 20]. Christensen is a bestselling author and a professor at Harvard Business School. Semiconductor consultant **STEVEN KING** holds a bachelor's in engineering from Worcester Polytechnic Institute. **MATT VERLINDEN,** also a consultant, is a graduate of the MIT Sloan School of Management. **WOODWARD YANG** is a professor of electrical engineering and computer science at Harvard.

KENNETH R. FOSTER reviews Donald A. Norman's book *The Design of Future Things*, which makes the case that some systems may be too smart for our own good [p. 17]. Foster, an IEEE Fellow, is a professor of bioengineering at the University of Pennsylvania and former president of the IEEE Society on Social Implications of Technology.

JOSON photographed Gordon E. Moore, recipient of the 2008 IEEE Medal of Honor, for this issue's cover and the profile on p. 38. As a nature lover, he found Moore's garden a great place to shoot. "It's so cool—the space feels like a big forest, with different weather conditions." Born in the Philippines, joSon now divides his time between New York City and San Francisco. He's shot photos for numerous magazines, and his work has been exhibited in art galleries throughout the world.



ROBERT W. LUCKY considers how power-law statistics apply to language in this month's Reflections column [p. 14]. Lucky, an IEEE Fellow, now retired, was vice president for applied research at Telcordia Technologies in Red Bank, N.J.

CARL SELINGER offers advice on avoiding the pitfalls of office politics in Careers [p. 16]. A private consultant with 40 years of experience in business, government, and academia, Selinger gives seminars to engineers on nontechnical skills. His 2004 book, *Stuff You Don't Learn in Engineering School* (Wiley-IEEE Press), has now been published in China.

CLOCKWISE FROM TOP LEFT: JENNIFER ARCHER; JOSON; STEPHEN LACKO; STEFANIE CASSIN; KENNETH R. FOSTER; PENNY LEVERITT

In seven months, a chip-fabrication plant reduced wafer-manufacturing costs by 12 percent and cycle time by 67 percent. How'd they do it?

spectral lines

It's Not Easy Being Lean

EVERYONE WANTS to be the Lance Armstrong of lean business these days. Healthcare operations want to get lean; manufacturers of every stripe want to get lean; even personal-improvement coaches want to help us get lean.

Lean manufacturing comes in many flavors. The most admired, and for long the least understood, is what's known as the Toyota Production System (TPS), an empirical method that aims for the complete elimination of waste and mistakes by continually and incrementally improving the process. TPS also makes that improvement—and thus the quality of the final product—the active responsibility of every person in the company, from the most junior worker to the CEO.

TPS is the driving approach behind the success of automotive powerhouse Toyota. The company began developing its system some 60 years ago, building on techniques set forth by the management expert W. Edwards Deming to improve mass production methods in the United States during World War II.

For decades, companies large and small have attempted to use Toyota's system to fix their own production problems. But these efforts have largely failed, and it hasn't been clear why. Cultural issues? Is TPS suited only to the automotive industry?

But now management guru and Harvard Business School professor Clayton M. Christensen and his colleagues have demonstrated that you can successfully apply TPS to the semiconductor industry. In "The New Economics of Semiconductor Manufacturing," in this issue, they describe how they won over the initially unenthusiastic staff of an unnamed integrated-device manufacturer's logic fab. In just seven months they got results that made everyone at the company sit up and take notice.

Why did it work in this case when it hasn't in so many others? For one thing, the fab committed itself wholly to the new way of working. You can't do TPS just a little or pull out the parts you like and toss the rest. You have to put the entire system in place. You have to give up your investment in the status quo and begin scrutinizing all your processes, both the ones that aren't working and those that are, not just once but every day, forever. You have to be willing to stop what you're doing to think about what's not working and accept that it's not working. It's hard to stay in a hypercritical mode for long periods of time without defaulting to blame and recrimination. These folks toughed it out.

And that brings us to another crucial TPS component: people. TPS must suffuse a company's culture in order for it to work. Employees need to feel that what they say matters and will be acted on. And TPS can't be a management mandate handed down from on high. Managers have to roll up their sleeves and jump into the fray. They must work hard to keep it going, training new employees, retraining current ones, and keeping everyone actively engaged, including themselves.

So you can imagine why there have been so many failures—TPS is hard to consistently do well over time.

SMALL STEPS forward are key to fab efficiency.
PHOTO: INTEL CORP.

Christensen and his colleagues also discuss how thoroughly applying TPS may result in what they call disruptions—a complete change in the way companies do their business. Christensen has long been interested in disruption and disruptive technologies, as his books *The Innovator's Dilemma* (2000) and *The Innovator's Solution* (2003) attest. The disruption he and his colleagues describe in their article would certainly be nerve-racking. But at a time when building new fabs costs billions and companies are scrambling to find new uses for their soon-to-be-obsolete fabs, disruption could also present much-needed opportunities for the struggling semiconductor manufacturing industry.

—SUSAN HASSLER

forum

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WHAT'S WRONG WITH THIS PROFESSION?

ROBERT W. LUCKY has long been the most lighthearted spokesman within our profession, so if he concludes that "the trends are bad"—most notably fewer young Americans choosing to become engineers—then we all have reason to feel discouraged ["U. S. Engineers and the Flat Earth," Reflections, March]. Of course, with ever more engineering jobs offshored, thousands of "emergency" visas issued to foreign engineers—and leaders of industry ascribing this to their need to pursue profits—we should be prepared for depressing news.

SAMUEL C. FLORMAN
IEEE Life Member
New York, N.Y.

The writer is chairman of Kreisler Borg Florman and the author of many books on engineering.

SHORTAGE? WHAT shortage? I read Robert W. Lucky's column with disbelief. False alarms about pending shortages of college science and engineering graduates have been popping up since the 1970s. It's just a crass attempt to keep the job market stuffed to bursting, all in the name of "competitiveness." The drop in science and engineering enrollment is a natural response to market forces, one that's been delayed two decades partly because of false alarms like those sounded by Lucky and government and university personnel who have a fiscal interest in keeping the classrooms and laboratories full.

There has been a glut of science and engineering graduates at all degree levels in the West ever since the Great University Expansion reached its peak circa 1975. This grad glut has caused stagnant salaries and poor prospects of advancement for hundreds of thousands of young Ph.D.s looking for tenure-track professorships. So let's not warp reality with talk of shortages.

LANCE NIZAMI
IEEE Member
Decatur, Ga.

I SUBMIT THAT we don't attract more U.S. students to engineering because of how some prospective students view our profession. We engineers are seldom viewed as being in touch, let alone in charge. We need to fix this negative perception. We need to recognize when we've put technology above human relationships and when we've idolized our designs without regard to their consequences. While technology can mitigate crises like climate change, resource depletion, poverty, and war, engineers must confront the fact that technology has made these problems worse—and made them global. The IEEE could have a leading role in this fix. It might start by giving social responsibility a more prominent position, along with better support for members. That support might help us resist lucrative salary offers from promulgators of weapons, spam, and porn, among other pollutants.

SCOTT WILEY
IEEE Member
Portland, Ore.

ROBERT W. LUCKY has captured the U.S. situation. Sure, you can put the onus on elementary school teachers, but what about overworked parents, greedy business leaders, and irresponsible elected officials? Popular media idolize entertainers and athletes and seem to regard engineering and science as toxic. Few parents in the developed countries want their children to become engineers, if being an engineer ultimately means competing against engineers in China or India on salary. It's more profitable to open a laundry, which requires no costly college education.

Following the greed lead, in the United States anyway, most graduating engineers are interested in business positions that offer quick economic gain, not a quiet, steady lifetime in the lab. And corporate America won't fund research—not because it can't, but because it must prostrate itself before the altar of the financial investment community, going for short-term results.

WAYNE BOWEN
Sequim, Wash.

CORRECTIONS

In the photo caption in March's Tools & Toys, we should have said that the Golden Temple is located in the state of Punjab, India.

In The Data for March, the unit for world production of copper should have been millions of metric tons.

METEORS ARE A HAM'S BEST FRIEND

IN THE Dream Jobs profile of Sigrid Close ["Star Struck," February] is the statement: "It turns out that meteors, as well as the ionosphere itself, disrupt radio signals." That depends on your point of view! While Close's concern is about communication between satellites and Earth, the ionosphere can *help* in communicating from one point on Earth to another. Many amateur radio operators routinely bounce their signals off ionized trails caused by meteors and thereby communicate over longer distances than would otherwise be possible.

MYRON A. CALHOUN *IEEE Life Member, Manhattan, Kan.*

MICK WIGGINS

WINTER WINDMILLS: A field of turbines in inner Mongolia is one of many new wind projects sprouting up as China enters its second year of multigigawatt growth.

PHOTO: CHINA PHOTOS/GETTY IMAGES

China Doubles Wind Watts

Trumping rivals in wind energy despite dismal returns

China is notorious for its accelerating consumption of coal, which will soon push it past the United States as a leading producer of greenhouse-gas emissions. But China is also rapidly becoming a world leader in wind power. Its fleet of wind turbines more than doubled in generating capacity in 2007, surging by over 3 gigawatts, according to the Global Wind Energy Council. That's less power capacity than China's coal sector adds per week, but it's enough to make China the third-fastest-growing wind market worldwide (behind the United States and Spain) and propel it to fifth place in the Global Wind Energy Council's annual capacity rankings (ahead of even wind-energy pioneer Denmark).

Sebastian Meyer, director of research for Beijing consultancy Azure International Technology & Development, predicts that China will add another 4 to 5 GW's worth of wind turbines in 2008, thanks in part to new standards announced late last year that mandate a greater reliance on renewable energy. If Meyer is right, China will close out 2008 with at least 10 GW of installed wind capacity—twice the country's target for 2010. Meyer says that wind farms are going up faster than China's grid operators can connect them to regional transmission lines. "Incredibly, up to 2 GW of the capacity out there at the end of 2007 was installed but not yet commissioned," says Meyer. He expects those wind farms to be connected soon.

What's truly unbelievable about China's dramatic investment in wind power is its endurance in the face of below-cost pricing. The government's primary mechanism for supporting the wind industry has been the awarding of wind-power concessions—agreements whereby the government purchases set amounts of wind energy from project developers. Bidding for the wind concessions—totaling 2.45 GW so far—has yielded an average price of 0.45 yuan (about 6 U.S. cents) per kilowatt-hour. That's break-even at best, according to industry experts. Many Chinese wind projects stay afloat by selling international carbon credits generated under

"...like carbonated water with an essence of natural gas" —HUNTER WAITE, principal investigator for the ion and neutron mass spectrometer on the *Cassini* spacecraft, describing the brew erupting from Saturn's moon Enceladus. *Cassini* flew through the spray on 12 March.

update

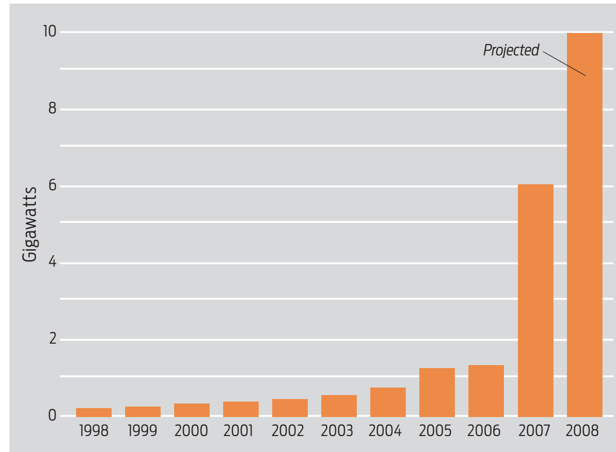
the Kyoto Protocol's Clean Development Mechanism, earning roughly another cent per kilowatt-hour.

A sweeping renewable-energy law enacted in 2005 failed to put China's wind industry on steadier financial ground. Regulations finalized last year by China's National Development and Reform Commission (NDRC) require large power-generating companies to incorporate at least 3 percent wind energy in their power portfolios by 2010 and 8 percent by 2020. However, the NDRC dashed hopes for a generous "feed-in" tariff akin to Germany's price premium, which fueled that country's world-leading wind sector by guaranteeing many years of fixed prices for any electricity sold into the grid. Instead, the NDRC opted to continue setting tariffs for wind projects on a case-by-case basis, guided by the pricing of nearby concession projects.

Policy analysts view China's rock-bottom pricing as a deliberate, though seemingly paradoxical, strategy to nurture local wind power developers. Li Jungfeng, secretary general of the Chinese Renewable Energy Industries Association, and Eric Martinot, a visiting professor at Beijing's Tsinghua University, wrote a report on the subject in November 2007 for the World Watch Institute. In *Powering China's Development: The Role of Renewable Energy,* they say that according to anecdotal evidence domestic developers have proved more willing to accept the low prices than foreign companies have.

On one hand, the price scheme has worked. Azure's Meyer notes that state-owned companies account for 88 percent of the wind power installed to date. And they are buying an increasing share of their turbines from domestic manufacturers. Meyer says that the top three Chinese wind-turbine manufacturers—Xinjiang Goldwind, Sinovel, and Dongfang—supplied over half of 2007's megawatts.

But the Chinese Wind Energy Association is worried about the industry's sustainability under relentless pricing pressure. As a result, the association may be the only renewable-energy trade group in the world calling for slower growth. Haiyan Qin, secretary general of the Beijing association, has no doubt that his industry will meet China's goal of installing 30 GW of wind power by 2020. In fact, he thinks the industry can do at least twice that. But first it needs to get its house in order. As Qin put it in an e-mail to *IEEE Spectrum*: "It is necessary to slow down the pace in order to guarantee the sound development of the industry." —PETER FAIRLEY



WIND POWER IN CHINA: The country's capacity is expected to surge by at least 4 GW this year. SOURCES: 1995–2007, GLOBAL WIND ENERGY COUNCIL; 2008 ESTIMATE, AZURE INTERNATIONAL TECHNOLOGY & DEVELOPMENT

TAIWANESE SOFTWARE SPOTS STOCK-MARKET STINKERS

TAIWANESE COMPUTER SCIENTISTS have developed a genetic algorithm—one that evolves to improve its performance—that can predict the impending demise or distress of publicly traded companies. The algorithm starts with 39 variables, such as sales growth rate and market value, and assigns weights to their influence. Over several iterations it optimizes the weights and then uses pattern-recognition routines to pick the losers. So far the algorithm has been tested only on Taiwanese companies, but the scientists say that it can evolve to work anywhere.

more at http://www.spectrum.ieee.org/may08/algorithm

TOP: NASA; BOTTOM: RICHARD DREW/AP PHOTO

OLAF KOWALZIK/GETTY IMAGES

Energy-Efficient Ethernet

Ethernet connections waste lots of watts. It need not be so

ETHERNET LINK speeds of 100 megabits per second or even 1 gigabit per second are typical right now in local area networks, but it's very unlikely that you need that much bandwidth all the time. Studies show that on average, people use their Ethernet links at full throttle less than 5 percent of the time. But the circuitry on the network-interface controller, the chip that connects your computer to the network, is always running at full speed, wasting power. In 2005, all the network-interface controllers in the United States—computers, switches, and routers all have them—burned through 5.3 terawatt-hours of energy, enough to keep 6 billion 100-watt lightbulbs shining all year.

"There's no reason to have a 1-gigabit link when there's no traffic on it," says Ken Christensen, computer science and engineering professor at the University of South Florida, in Tampa. Christensen and Bruce Nordman, a researcher at the Lawrence Berkeley National Laboratory, in California, have devised one of two schemes vying to become a standard that if put into practice would save some of the wasted watts. Their seemingly simple solution: adapt the Ethernet link's speed to match a device's needs. If you were checking e-mail, for instance, 100 Mb/s would be enough, but the network controller would shift to 1 Gb/s when downloading a large file. The researchers described the concept, called Adaptive Link Rate, last month in *IEEE Transactions on Computers*.

At the low data speeds, the network controller chip's circuits would work at slower clock rates, and some might be turned off, cutting power use. Christensen and Nordman estimate that with networking devices in homes, offices, and data centers running at 1 Gb/s, switching to 100 Mb/s whenever possible could save more than US $300 million in energy costs.

The savings would be even greater if the links were switching between 10 Gb/s and 100 Mb/s. Ten-gigabit links—expected to be widespread by 2010—use 10 to 20 W more power than 100 Mb/s links, while 1 Gb/s uses about 4 W more.

But Christensen and Nordman's concept will take some effort to implement. Switching between Ethernet speeds is time-consuming. "When you change link rate today, you have to drop the link and reestablish it, which takes [up to] 2 seconds," says Nordman.

However, rate switching would have to happen in less than a millisecond to be practical. That means researchers will need to come up with a much faster protocol for the two ends of an Ethernet link—say, a PC and a switch—to coordinate their link rates.

The industry is weighing the Adaptive Link Rate scheme against another one, hatched at Intel, which promises to be even more energy efficient. Called low-power idle, it proposes transferring data on an Ethernet link at the highest possible rate and then putting the network controller chip into a sleeplike state. "You're better off sending data faster and getting to sleep quicker, which allows you to save more power over the long haul," says Robert Hays, a strategic planner for networking products at Intel.

The trouble is that turning on a dormant network card quickly is a challenge. Still, for link speeds up to 1 Gb/s, Hays says, turning circuits on and off is easier than switching between rates. An IEEE standards task force recommended the Intel scheme for 1-Gb/s links.

But for faster, 10-Gb/s links, where there is more potential for power savings, it's not yet clear which of the schemes would be easier to implement and would save more power.

No matter what scheme the industry chooses, a complete redesign of the network-interface controller system is needed, says Hugh Barrass, a technical leader at Cisco. "[We] should expect to take two to three generations before equipment gets the most efficient it can be," Barrass says.

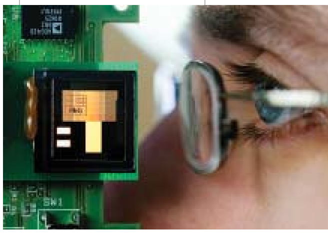
—PRACHI PATEL-PREDD

news brief

I SEE YOU

Researchers from the Fraunhofer Institute for Photonic Microsystems plan to demonstrate an organic LED built on a CMOS chip this month at the Society for Information Display. The technology should allow the integration of light-emitting pixels and light-sensing elements, yielding a combination of camera and display in one chip.

PHOTO: FRAUNHOFER INSTITUTE FOR PHOTONIC MICROSYSTEMS



update

CHANGING MINDS: A brain implant for depression is in the works.
PHOTO: ST. JUDE MEDICAL

A Difficult Time For Depression Devices

Mood-disorder treatment has eluded the makers of brain stimulators. Will the next round of research fare better?

BRAIN-STIMULATION devices for treating depression have faced unexpected setbacks. To serve the 40 million or so sufferers who fail to respond to antidepressant drugs, a few companies have tried to treat the disorder with electronic implants and electromagnets. These therapies, however, have stumbled en route to the doctor's office.

To take a crack at those intractable cases, experiments exploring five device therapies will start this year. In total, nine different technologies are now under investigation in at least 27 human trials.

The largest new study, done by St. Jude Medical, in St. Paul, Minn., will be the first major human trial of one brain implant that showed dramatic early results. A device inserted near the collarbone sends pulses of current to electrodes placed inside the brain. At the other end of the spectrum, Northstar Neuroscience, in Seattle, will enroll patients in a small, exploratory study. Northstar's technique involves implanting a postage-stamp-size electrode on the surface of the brain.

But if history serves as a guide, the path will not be easy for either company. In the United States, which has both a large market and tough approval standards, only two depression devices are now in clinics. One is electroconvulsive therapy, which precedes the U.S. Food and Drug Administration's governance. The other is Houston-based Cyberonics' vagus nerve stimulator. Here, a pulse generator in the chest sends current to an electrode coiled around a nerve in the neck to indirectly alter brain regions believed to control mood.

A factious debate leading up to the device's approval pitted the FDA's management against scientists and was a sign of worse things to come: the United States' main government-funded health insurers soon decided that the device was not useful enough to earn reimbursement. Private insurers generally follow the lead of those agencies, so for the US $25 000 procedure, the news was crippling.

The approval process has not been any smoother for Malvern, Pa.–based Neuronetics, whose device transmits a magnetic field into the brain from an external coil. This induces a current that also seems to assuage depression. Unlike the others, this method involves no surgery, which makes it safer and more palatable to the patient. Even so, in January 2007 an influential FDA advisory panel gave it an unfavorable review, again claiming that its benefit to patients is unproven.

Northstar, too, has been knocked off course—and before it really got started. A trial of its stimulation device failed to prove that it surpassed an existing alternative. The goal was stroke rehabilitation, but the outcome will likely impinge on the depression investigation anyway: Northstar cut one-third of its workforce in response. Helen Mayberg, a neurologist at Emory University who invented the deep-brain stimulation technique that St. Jude is now testing, wonders if the companies' troubles will haunt the next round of research. "You have to ask, where did they go wrong?" she says.

The basic problem is that the changes induced in a stimulated brain are poorly understood, in part because depression itself is exceedingly complex. Linda Carpenter, a psychiatrist at Brown University, explains that 100 patients might exhibit 20 different sets of symptoms.

Furthermore, crafting the perfect pulse is beyond the reach of today's psychiatry. A pill has one main parameter—dosage. These devices have at least five: the intensity and frequency of stimulation, the duration of each pulse and the intervals between them, and the spot being stimulated.

Checking every parameter in hundreds of patients would bankrupt most medical-device makers. "There are no deep pockets in this game," says Eric Wasserman, a clinician in the National Institutes of Health brain-stimulation unit.

As Mayberg sees it, "We may look back in 10, 15 years and say, we did *what* to the brain? But it's a definite paradigm shift." In the meantime, St. Jude and Northstar hope to avoid the pitfalls of their predecessors.

—SANDRA UPSON

Ausra Makes Solar Thermal Simple and Cheap

A start-up decades in the making may accelerate the solar-energy revolution

FLAT, CHEAP, AND UNDER CONTROL: Ausra's steerable flat mirrors focus sunlight on a tube to make steam for a generator. PHOTO: AUSRA

SOLAR-THERMAL POWER has never seemed as technologically smart as photovoltaic technology. After all, a Neanderthal man could warm himself in the sun, but it took Einstein to explain the photoelectric effect.

But these days the idea of using sunlight to heat fluids to generate electricity is suddenly looking like a bright idea. At least 10 solar-thermal power plants are being developed for installation in the United States, and another 17 are under construction or being planned in Algeria, China, Egypt, Israel, Mexico, Morocco, South Africa, and Spain. With a typical plant generating somewhere between 50 and 500 megawatts, that's a lot of clean power due to come online. (New photovoltaic installations worldwide totaled a record 2826 MW in 2007, according to Solarbuzz.)

There are lots of ways to build a solar-thermal system, parabolic troughs or dishes being the most familiar. But a former Australian academic, David Mills, founder of the solar-thermal firm Ausra, in Palo Alto, Calif., thinks he has a better idea, and at least one major utility—Pacific Gas & Electric, in San Francisco—agrees. In November, the utility signed an agreement to purchase power generated by a 2.6-square-kilometer 177-MW power plant Ausra is building in the Nevada desert. Ausra says it has many more such deals in the works.

Mills's design, called the Compact Linear Fresnel Reflector, uses much less land than others. The mirrors appear to be solid but are actually made up of many smaller, movable reflectors, each with a slight curve. The system uses nearly flat mirrors at ground level that focus the sun's light onto water-filled steel tubes. When the water boils, it directly drives a steam turbine to generate electricity. Typical solar-thermal systems use heat transfer; water- or oil-filled tubes pass the heat to another system, which then boils water to drive steam turbines.

"I have a favorable opinion of [Ausra's] technology, largely because of the relative simplicity of manufacturing flat mirrors compared with parabolic mirrors. Also, because the mirrors are closer to the ground, they are less subject to wind loads," says Michael Locascio, a senior analyst with Lux Research, in New York City.

Last April Ausra powered up the production line at a 12 000-square-meter manufacturing plant in Nevada. It's the first facility in the United States dedicated to producing the components of solar-thermal systems, including reflectors, towers, and specially insulated steel tubes. The new factory can build enough equipment to fill more than 10 km^2 with solar-thermal collectors annually, enough to produce 700 MW of power or to power 50 000 homes. Eventually, Mills expects Ausra to sell equipment to others; for now, Ausra will consume the output.

Ausra sounds like a young company on the fast track, and in a way it is. It got its first round of venture capital financing last year—US $43 million. But in another way, Ausra's been slowly building for decades. Mills has been working with solar energy since the 1970s. Back then he was a principal research fellow at the University of Sydney, doing work in optics. There he started a research program to develop advanced coatings for evacuated-tube solar collectors, cleverly constructed glass tubes that let solar energy in but don't let heat out. Today his tubes are widely used in water heaters in China.

In 2006, John O'Donnell, a serial technology entrepreneur, contacted Mills. At first Mills told him, basically, to get lost. But O'Donnell was persistent, and in October of that year, he convinced Mills to come to California for a meeting with venture capitalists. Just three months later, Mills left the house in Sydney where he'd lived for more than 20 years and moved to Palo Alto; his wife and children followed a month later.

These days he heads up R&D for Ausra; until recently he ran the company's engineering efforts as well. "I'm 61," he says. "It's a bit late in life to do a start-up, but when you work at something all your life, you do hope something comes of it and that you can influence change." —TEKLA S. PERRY

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

the big picture

"SUPER BOWL" CANCELED?

This massive, steerable parabolic dish, which in 1957 tracked the ascent of the rocket that launched *Sputnik I* into space and is sensitive enough to pick up a cellphone call from the surface of Mars, may soon be out of the astronomy business. The dark clouds in the picture that hover over the Lovell Radio Telescope, located at the University of Manchester's Jodrell Bank Observatory, in England, are apropos. Government funding for a program that would keep the telescope peering into the heavens may soon be slashed. Lovell is a protected landmark, so it won't be torn down. Instead, the dish could be repurposed as a giant movie screen, displaying stars of a different sort than those for which it was originally designed.

PHOTO: CHRISTOPHER FURLONG/GETTY IMAGES

reflections BY ROBERT W. LUCKY

Zipf Drive

I'VE LONG been fascinated with the omnipresence of power-law statistics in natural and social phenomena. A good example is Zipf's Law for the usage of English words, named for the 20th-century linguist George Kingsley Zipf. The most common word, *the,* is used twice as often as the second most popular word (*of*) and three times as often as the third (*and*). Similarly, the *n*th most popular word has a relative frequency of use of 1/*n*.

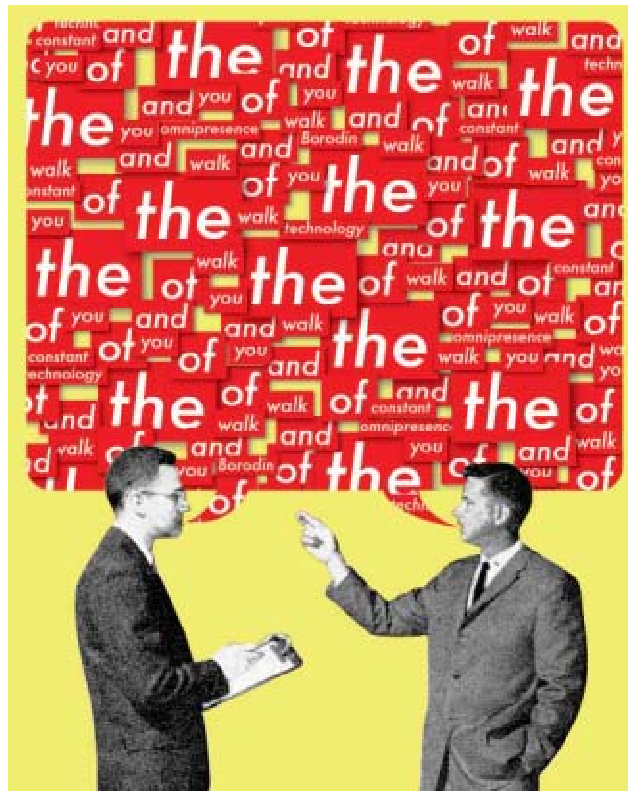
Thus, the curve of popularity versus rank shows a steep decline at first, followed by a long tail that looks rather flat when plotted on a linear scale. (On a log-log plot, of course, this becomes a straight line.) A word like *omnipresence* is way out on the tail, at popularity position 74 228, right before the word *Borodin* (the Russian composer), according to WordCount (http://wordcount.org).

All of the most common words are short, resulting in a very efficient transmission of information. I imagine our distant ancestors sitting around the fire, drawing information-theory equations with sticks in the mud to come up with an optimally parsimonious language, after which they would decide that they shouldn't have used the word *parsimonious* (popularity number 49 309) when something like *concise* would have sufficed.

All this is to say that our vocabulary is rather a perfect blend—100 or so popular words used in everyday conversation and writing, together with about 100 000 more esoteric words that get sprinkled in for effect or special purpose.

Many other phenomena exhibit power-law (that is, polynomial) statistics—cities ranked by population, individuals by wealth, earthquakes by strength, Web sites by number of hits, books by online sales. I would even imagine that it applies to something like the distribution of knowledge in electrical engineering. All of us know Ohm's Law, for example, but perhaps only a tenth of us are familiar with the basic concepts in communications. Then maybe only one engineer in 1000 is familiar with a particular protocol, and only one in 100 000 might be conversant with a particular paper in a specific *IEEE Transactions*. But this is what makes the world go round; we have a lot of things in common, but there is a long tail of specialties that makes each individual unique.

Although power-law statistics have been long known, the subject has gotten much recent attention under the name "the long tail," a phrase coined by Chris Anderson, the editor in chief of *Wired* magazine, in an article in 2004. Discussions have been prompted by the difference between sales in the physical world, where inventories are limited to the popular items, and those in the virtual world of the Internet, where there is no inventory constraint to eliminate all the rare items



on the long tail. In the virtual world, the many small sales out on the long tail approximately equal the sales of the few most popular items.

In most cases there are fundamental reasons that statistics behave like a power law. For example, even though it might seem as if individual choices should be uniformly distributed among alternatives, an individual's choice is often influenced by the choices of others. This explains our herdlike behavior, with a flocking around popular choices and a long tail of individual dissent.

How could it be otherwise? Suppose for a moment that power-law statistics weren't the norm and that choices were uniformly distributed. What would the world be like? With all 100 000 or so words equally likely, books would be long and turgid but of little interest, because there would be so few subjects of common concern. And of course it would be almost impossible to learn a foreign language.

Population would be uniformly scattered about the Earth. There would be no cities, and whole countries would be like New Jersey, where I have to describe my home's location by the nearest exit number on the Garden State Parkway. For better or for worse, wealth would be uniformly distributed, and perhaps neither cathedrals nor slums would be so prevalent.

I'm sure that you can provide your own suppositions, but perhaps we could all agree that we wouldn't want to inhabit such a world. Our ancient ancestors around the fire figured this out a long time ago. ❑

LAURA H. AZRAN

Each of us must contend with office politics, because human beings are political animals, and we form alliances, negotiate deals, demand tribute, and wreak revenge

careers

I HEARD THAT! What people are saying about you can help you to improve your diplomatic skills.

PHOTO: AIDON/GETTY IMAGES

SURVIVOR: THE OFFICE

You can't avoid office politics, so you might as well learn the rules of the game

WITH THE U.S. presidential election season upon us, we engineers—and not only those of us who live in the United States—are reminded daily of why we never wanted to get involved in politics. Even so, each of us must contend with politics of a different kind—office politics—because human beings are political animals and we form alliances, negotiate deals, demand tribute, and wreak revenge.

Here is my short list of political dos and don'ts:

Learn how your organization actually works. This may bear little resemblance to the formal organizational chart. One junior engineer in her first job began noticing who got cc'd on office memos, reasoning that they were the key people. She found out who all these people were and their roles or responsibilities and made it a point to meet with them informally. She credits this with boosting her early career.

Find out what your reputation is and what people say about you. Even if you don't engage in gossip, others will, and the resulting misperceptions can hurt you. Soon after my unit was moved to a new department, my manager told me she was surprised to hear that some people in the new area were saying bad things about me. The most serious complaint was that I was difficult to work with and combative. We decided that I would try to be especially cordial and diplomatic, particularly with key staff members with whom we were developing projects. She monitored the situation over several months and reported back that my reputation had significantly improved.

Consult with people and identify common objectives. Ask them, "What will it take for you to support this?" Maybe you'll need to revise the scope of a project or accommodate their desires to be involved in it. I was once working with our engineering department to review the technical scope of an airport project and held a meeting to discuss their comments. The lead engineer asked me, in front of everyone, if I was going to listen to their comments—because no one ever had. I assured him that every comment they suggested would be incorporated unless we agreed it didn't fit. He became a huge supporter of the project. Years later, even though I've left the organization, he speaks enthusiastically about that project whenever we meet.

Get to know the people who are against you or your projects. One time I got a phone call from a traffic engineering manager who was very angry with me over a project I was running. While I might have talked him down or had an argument, instead I listened to his points and suggested we meet that day for lunch at his location to talk it out. We reached an agreement, and the project went smoothly.

Build strong personal relationships with key people. This will give you a sounding board within the organization to get feedback and advice on how you're doing, what you need to do to get something done, and how to identify the pitfalls or persons who will object. Get a mentor in your organization, someone more experienced than you, who can give you the scuttlebutt on how to proceed and give valuable advice to questions like "What's your take on this situation?"

Publicly recognize the good work of others. Always say thank you for a job well done. Get known for being a professional with whom everyone wants to work. Be a manager who develops his or her people for promotion. You will build a cadre of people in the organization who will talk you up and support you when you need it, even if you don't know it. —CARL SELINGER

books

In Defense of Dumb

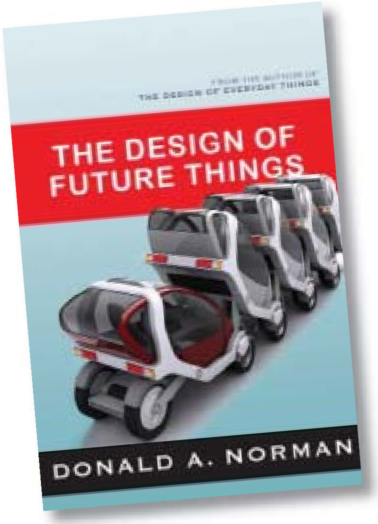
Gadgets don't necessarily get better when you give them brains

"I AM A technologist," says Donald A. Norman in his brief and insightful book *The Design of Future Things*. "I believe in making lives richer and more rewarding through use of science and technology. But that is not where our present path is taking us."

Norman, a professor of electrical engineering and computer science at Northwestern University, became famous for his book *The Design of Everyday Things* (first published in 1988 as *The Psychology of Everyday Things*). In it he called for "user-centered design," a way to make everyday products easier to use and more foolproof. Now he turns to seemingly futuristic technologies that in fact may not be so far away. Many of Norman's examples involve automobiles. For example, some new cars are now equipped with an adaptive form of the familiar cruise control. Like the old form, it keeps the car going at a constant speed; unlike the old form, it automatically slows the car when it gets too close to the car in front of it.

But that extra automation can lull the driver into complacency, Norman says, taking over when the going is easy and unexpectedly giving up when things become difficult. Norman describes how one of his friends had a close call after driving for some time at low speed on a congested highway and then turning onto an exit ramp. The car suddenly accelerated because of the adaptive cruise control, which he had forgotten to disable. A better-designed system would have reminded the driver that the control had been activated. In fact, Norman thinks, automobiles should be designed to appear less safe than they actually are to keep the driver on guard, a suggestion not gladly accepted by some of his automobile-industry clients.

Intelligent systems, he argues, should be understandable and predictable, and when something goes wrong they should send messages that get the user to make the right response intuitively. As an example of good design, he cites the aeronautical system that vibrates the control yoke to warn the pilot of an impending stall. For bad design he offers the writing recognition system in Apple's old Newton personal digital assistant, which could turn a carefully written word into nonsense without giving the user any clue as to how to correct the problem.



THE DESIGN OF FUTURE THINGS
By Donald A. Norman;
Basic Books, 2007; 231 pp.; US $27.50;
ISBN: 978-0-465-00227-6

It's wrong, Norman argues, to try to make machines too smart. A car with an automatic navigation system that chooses a scenic route when it thinks the driver is in a good mood is unlikely to succeed, he says, because cars will probably never be good at reading human intentions. Instead, he wants machines that augment human capabilities—for example, robots that allow auto-assembly workers to manipulate heavy objects while receiving tactile feedback, to make their operation intuitive to a worker.

The Design of Future Things is short, easy to read, and clearly meant for a lay audience—the very people who most need to be warned not to expect too much from automation. No doubt most engineers would agree with his criteria for good design. The problem is that many subtle usability issues manifest themselves only after somebody has gotten into trouble with a product; that's why designers, consumed by the rush to bring new products to market, overlook them.

Norman inhabits the very particular world of designers of high-end consumer products. Such products chase those so lost in overconsumption that they can contemplate a refrigerator that locks its doors when a dieter approaches. Where is the guru for the bottom billion people in the world's economic order, who have too little to put in their nonexistent refrigerators in the first place? —KENNETH R. FOSTER

mini-profile

By Susan Karlin

JEANNINE MOSELY: PAPER SCULPTOR

It was her Menger sponge, a cube measuring 1.5 meters (5 feet) on one side and made from 66 048 folded business cards, that put her on the map, but Jeannine Mosely has loved origami since the age of 5. It was the perfect background for an MIT Ph.D. in electrical engineering and computer science and a career in three-dimensional modeling. She says she loves to breathe life into numbers: "You can see a mathematical theorem or formula made real when you create a new model." See her work at the Peabody Essex Museum in Salem, Mass., through 8 June; at the Siggraph 2008 Convention in Los Angeles, in August; and online at TheIFF.org, Creased.com, and PEM.org.

PHOTO: RICK FRIEDMAN

"Very rarely does a good mashup come together effortlessly. It's not just slapping a vocal track on top of an instrumental and calling it a day"—ADRIAN ROBERTS, OF DJS ADRIAN AND THE MYSTERIOUS D

ONE COUPLE, TWO CHANNELS: Adrian and Deirdre Roberts love to combine music, even the bootlegged kind.
PHOTO: LEO HERRERA

The Mash Monsters

DJs Adrian & the Mysterious D sing the praises of the mashup, a do-it-yourself combo of existing music that has copyright lawyers licking their chops

A SKULL AND crossbones flies today over the mashup, the world's newest form of pop music. Like the punk rock revolution it harks back to, it has an outlaw do-it-yourself ethos, but this time around, instead of electric guitars and torn clothing, the crucial component is software.

A mashup consists of overlaid (and typically illegally sampled) snippets of preexisting songs. The best ones offer up equal parts musical parody and dance-floor-filling cheeky commentary—think the "Imperial Theme" from *The Empire Strikes Back* colliding with Middle Eastern–flavored techno from electronica artists The Chemical Brothers.

The form's tireless evangelists are DJs Adrian and the Mysterious D, otherwise known as Adrian and Deirdre Roberts, husband-and-wife producers based in San Francisco. They host a monthly party called Bootie (for "bootleg") in San Francisco, Los Angeles, New York, and the online virtual world Second Life. Here they play both their own material and some of the top mashups from around the world, as culled from Web sites like Mashup Charts (http://mashup-charts.com) and Mashupciti (http://mashupciti.com). Sister Bootie events have also cropped up in Mexico City, Munich, and Paris. The events are listed at http://bootieusa.com.

Both husband and wife are avid music fans with omnivorous tastes. Adrian is the techie one, having earned a bachelor's degree in radio and television and worked in both audio and video since the late 1980s. He says the key to making a mashup is mastering an off-the-shelf music-mixing program, such as Sony ACID Pro (Windows) or Ableton Live (Mac). Audacity, an open-source program, is a good, simple, and free alternative.

"Very rarely does a good mashup come together effortlessly," Adrian says. "It's not just slapping a vocal track on top of an instrumental and calling it a day." Merging many songs seamlessly into a new composition, particularly one that takes on new meaning as satire or commentary, can require days or weeks in the studio. Some particularly ambitious producers add video too. "Usually, the audio part is done first, and then videos of the songs that are mashed up are edited together to sync up with the audio," he says.

Of course, it all begins with the hunt for raw material—the most challenging part of which is locating unadorned vocal tracks. One trick, Adrian says, is to comb through bands' videos or concerts on DVD. He says that if the music was produced in Dolby 5.1 Surround, you often find the vocals in the center channel.

Some artists also release a cappella versions of their songs, encouraging fans to mash it up. The most famous example is a Jay-Z *Black Album*/Beatles' *White Album* mashup, *The Grey Album*. In 2003, rapper and hip-hop mogul Jay-Z released an a cappella version of *The Black Album*, encouraging remixers and mashup artists to mix his vocals into others' music. When New York DJ Danger Mouse (Brian Burton) released *The Grey Album* online in 2004, it provoked a cease-and-desist letter from the Beatles' recording label, EMI-Capitol.

The mashup underground views such a letter as a badge of honor, says Deirdre. For those of a less buccaneering nature, though, such a letter may come as a bit of a shock. But don't worry—if you're doing it strictly for private enjoyment, your behavior would be actionable only under the most draconian legal interpretation, says Paul Rapp, an expert on copyright at Albany

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

Law School, in New York state. It would be like suing children for singing "Happy Birthday to You"—still under copyright after all these years. Those who should beware, Rapp says, are mashup producers who take their material onto the Internet and establish a cult following.

Until the courts begin to rule on how mashups fit into the fair use provisions of copyright law, establishing what's legal and what's not, DJs A+D say they're happy to continue dancing their delicate dance through the world's popular music catalog, Jolly Roger hoisted high. —Mark Anderson

tools & toys

N800 Fights the Bad Guys

If you want to find the vulnerabilities in your system before the black-hat hackers do, Nokia's programmable handheld is just the ticket

Last month we took a look at the Nokia N800 as a platform for thought experiments in user-programmable ubiquitous computing ("Hacking the Nokia N800," April). But the tiny, reasonably powerful device turns out to be useful in professional as well as personal contexts. A good example is the assessing of system security.

In the days of wired-only networks, an engineer would test a system's penetrability by trying to hack in through firewalls or terminal servers or through social engineering—that is, convincing gullible employees to help him. Now anyone with a pocket-size device can carry out the same kinds of attacks wirelessly.

The further up they are on the corporate ladder, says Justine Aitel, CEO of Immunity, a security consulting company in Miami Beach, the more likely that managers will want all-wireless offices. And with ill-secured wireless networks abounding, all a system infiltrator—or "cracker"—has to do now is get a package the size of a paperback book into a company's mail room and headed for an executive's desk.

SNIFFING FOR intruders in wireless networks—just another programmable job for the Nokia N800. PHOTO: JUAN IGNACIO IGLESIAS; SCREEN SHOT: IMMUNITY

Immunity sells N800s preconfigured with a downsized version of Canvas, the company's laptop penetration-testing tool. The program can run through a sequence of hundreds of known PC and server vulnerabilities once it finds an unguarded wireless connection. Then, with access to the Internet as well as local machines, the device can presumably send a detailed report home. Screen shots of the CEO's PC make for especially compelling presentations, Aitel says. Or perhaps, considering that the preconfigured gizmo lists at US $3600, a penetration tester might want to wangle a quick trip inside, with the N800 concealed in a pocket or briefcase.

Those with more of a do-it-yourself spirit can download open-source tools and even use the N800's own software to do security analysis. Keith Parsons, who teaches wireless security at the Institute for Network Professionals, in Orem, Utah, says that he often surveys the extent of a wireless network's coverage by plugging in a set of earphones and walking around with the N800 connected to a favorite Internet-radio stream. Wherever he can hear audio, a cracker can connect to the network.

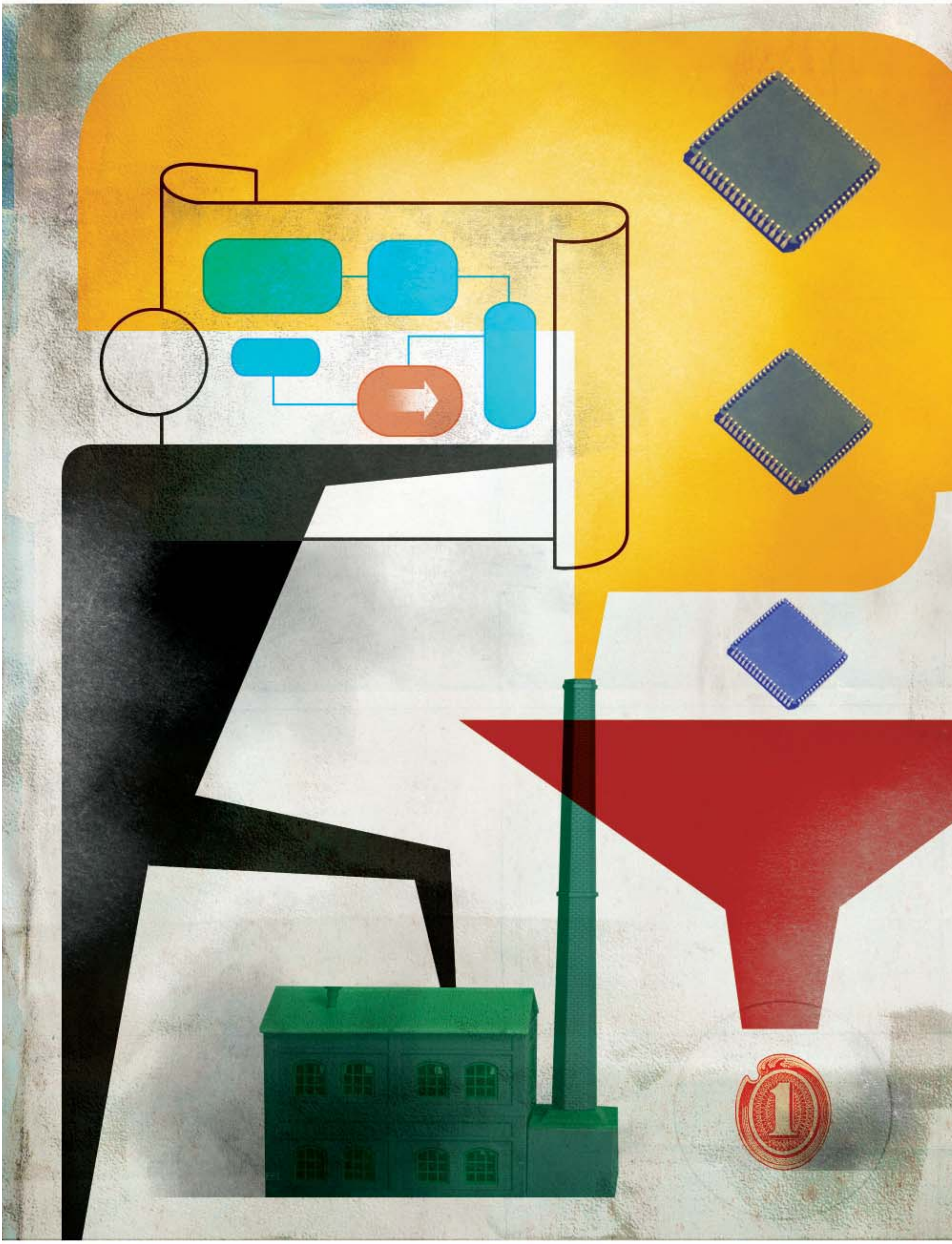
One step up is Kismet, which detects all wireless networks within range and logs network traffic for open networks (or those encrypted networks for which it has a key). Kismet can also detect certain attacks from other machines.

Aircrack, an open-source suite of attack-and-analysis tools, can monitor encrypted networks as well as unencrypted ones. It uses one attack that can discover the password for networks secured with Wired-Equivalent Privacy at a 50 percent success rate after reading 50 000 packets, rising to 95 percent after 85 000 packets. That can take as little as 2 minutes if, for instance, an attacker broadcasts faked data to stimulate additional network traffic. Even with the N800's late 20th-century-style CPU, notes Immunity software developer Alex Iliadis, the computing part of the attack is well within its capabilities.

Further up the open-software hacking food chain is Metasploit, a framework for security exploits. The modular software includes sets of methods for gaining initial access to a target system, tiny chunks of code for downloading more complex attacks into the target, and "payload" modules that can do pretty much whatever a programmer wants with a computer once it's been thoroughly compromised.

None of this gives me warm feelings about the safety of my own little wireless network. Maybe I'll fire up a spare machine running Kismet and some other tools, just to see whose packets are dropping in for a visit.

—Paul Wallich



SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

THE NEW ECONOMICS OF SEMICONDUCTOR MANUFACTURING

The Toyota Production System has been applied to chip making. The electronics industry may never be the same

By Clayton M. Christensen, Steven King, Matt Verlinden & Woodward Yang

ILLUSTRATIONS BY STUART BRADFORD

THE SEMICONDUCTOR industry is undergoing a sea change. It's being split into haves and have-nots, and it has become much more difficult for everyone to make a profit. Never have so many smart people worked so hard for so little money.

Walk into a multibillion-dollar chip-fabrication plant—a fab—and you may very well get the impression that the industry is headed for a spectacular meltdown. One of the first things you'll see is a bay the size of two basketball courts packed with equipment for projecting a lithographic design onto wafers. Nearby, you'll find a towering bin, called a stocker, filled with wafers waiting to be processed by this equipment. The wafers are worth from US $10 million to $100 million—all of it idle inventory.

Why? To amortize the $5 billion investment in a fab over a five-year schedule costs more than $3 million a day. Conventional wisdom holds that to generate that much money you must keep all the equipment running all the time, even if that means creating large unused queues of wafers. What's more, to justify that scale, you have to produce a semiconductor product in volumes of at least 5000 to 10 000 wafers per month.

More than anything else, Moore's Law has been responsible for the gigantic costs. It takes huge amounts of capital to support the incessant cycles of investment and obsolescence that keep Moore's Law on the march. That rapid cycling explains why a company's shining jewels can turn into white elephants in just five years.

Although industry giants like Intel and Samsung work on a vast scale and can therefore make these huge investments work for them, smaller companies (and even some sovereign states) can no longer afford to play the game. A massive restructuring in the industry is forcing them to consolidate or outsource production in order to gain sufficient scale to compete.

Every month new alliances and divestitures bring fresh evidence of this restructuring. In 2006, Texas Instruments announced that it would partner with foundries to codevelop future process technologies based on line widths (the smallest feature on a chip) of less than 45 nanometers. In 2003 and 2006, respectively, Motorola and Philips—iconic companies in the industry—spun off their semiconductor operations entirely. In 2006, LSI Logic (now LSI Corp.) acquired Agere Systems and continues to struggle. Intel sold its communications and application-processor business to Marvell Technology Group. Advanced Micro Devices, its cash flow and its competitiveness in question, acquired ATI Technologies in 2006.

All these strategic moves were meant to recover the growth and profitability of the past. But none of them have done so.

There is, however, a glimmer of hope, and it comes from an unlikely source: the Toyota Motor Corp. For more than 30 years, Toyota has followed a production system that has enabled it to increase quality, double capacity, produce a wider variety of models in a given factory, and change the mix on a dime. Last year Toyota made more cars than any other company, surpassing General Motors.

Even more important, Toyota's approach to mass production has produced bountiful profits. In 2005, it earned more than all the other auto manufacturers in the world combined. Yet although many scholars and executives have scrutinized Toyota's plants and production methods—GM went so far as to open a joint venture with Toyota in California—no one has yet been able to fully replicate its success.

In early 2007, we had the opportunity not merely to emulate Toyota's system but to apply its principles to a logic fab belonging to an integrated device manufacturer (IDM). As consultants, we are not at liberty to divulge the company's name; however, it's safe to say that the company is highly competitive—that is, it has survived and prospered by pursuing Moore's Law, always remaining at the forefront in technology and operational excellence. But Moore's Law was turning this jewel of a fab into a white elephant while the equipment was still relatively new.

In just seven months, the organization was able to reduce the manufacturing cost per wafer by 12 percent and the cycle time—the time it takes to turn a blank silicon wafer into a finished wafer, full of logic chips—by 67 percent. It did all this without investing in new equipment or changing the product design or technical specifications. And this short

experiment has exposed only the tip of the iceberg. We believe that these early results point to what we call the new economics of semiconductor manufacturing and that this will have a profound and lasting effect on the industry and create new opportunities for growth.

THE PRINCIPLES and philosophy of the Toyota Production System (TPS) that we applied were first described in 1999 by Steve Spear and Kent Bowen, then at the Harvard Business School, in their article "Decoding the DNA of the Toyota Production System" in the *Harvard Business Review*. They noted that Toyota trains its workers to treat any problem that arises as an opportunity to learn. Toyota designs and redesigns work according to a rigorous process to examine the current state of production and generate hypotheses on how to improve it, together with a highly specified expected outcome.

It's an empirical approach based on iterative experimentation, one that long escaped the many Toyota watchers who typically fell into the trap of confusing the company's tools—such as kanban cards, used to order parts—with its principles.

Spear and Bowen distilled TPS into four rules, which in summary are (1) highly specify activities, (2) clearly define the transfer of material and information, (3) keep the pathway for every product and service simple and direct, and (4) detect and solve problems where and when they happen, using the scientific method. When we present these rules, even in their fully detailed form, clients generally protest that they "do it that way already." But on closer examination—while auditing their fabs—we often find something quite different [see sidebar, "The Toyota Production System Sanity Check"].

Here are examples from our work.

The first rule, on activities, states that "all work shall be highly specified as to the content, sequence, timing, and outcome." At the fab we studied, maintenance technicians were supposed to clean the etch chamber from top to bottom, but we observed that sometimes they did it from bottom to top. That order wouldn't have been so bad if it had been followed consistently, because the behavior would have become a new set point around which further improvements could be based. But in fact, the method of cleaning changed unpredictably. There was so much random variability in the work that nothing could be learned from the results.

The next rule states that "every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses." This rule was violated when, for example, a worker—we'll call her Jane—operated a deposition-process machine that received wafers supplied by another worker, whom we'll call Bill. That arrangement made Jane Bill's "customer." In a properly ordered system, he'd send her wafers when—and only when—they were needed. In practice, he sometimes had no wafers when she needed them, and at other times he encumbered her with wafers she could not use. Jane then had to throw those excess wafers onto the costly pile of inventory.

The third rule states that "the pathway for every product and service must be simple and direct." This rule was violated when a cassette of wafers showed up at a bay equipped with 10 identical process tools, any one of which could be used to process the cassette. But which tool were the workers supposed to use? No one could say offhand because the path was not simple and direct, and the critical decision was left to the operator on the floor.

Why does this indeterminacy matter? First off, not knowing the direct path from the outset makes it hard to reconstruct that path later on, if a batch of wafers should show defects. Even worse, ignorance of the path prevents the system as a whole from discovering a defective machine in time to prevent a recurrence. Memory fades quickly, and when workers are able to avoid a malfunctioning machine without fixing it immediately, they lose opportunities to learn and improve. The Toyota system requires that the problem be addressed locally, immediately, and intensively by clearly defined actors, not just any "expert" who happens to be available.

The fourth rule states that "any improvement must be made in accordance with the scientific method under the guidance of a teacher, at the lowest possible level in the organization." One worker found a better way to get a customer the material he needed. He helped the customer pull the material from his supplier instead of having the supplier push it to the customer, as had been done before. The worker had to analyze the current state of things, document it, and formulate a hypothesis that included an experiment with an expected outcome that could be measured and compared with the actual outcome. Such problem solving engages everyone and creates an army of scientists engaged in continual improvement and organizational learning.

IMPLEMENTATION OF THESE ideas is harder than it may seem; it requires a certain adjustment of thinking. We have studied many companies that were trying to increase their operational efficiency. In the beginning, they typically lump TPS under the rubric of "lean" manufacturing. But while many lean techniques have great merit, the Toyota system is strikingly different.

Most semiconductor companies undertake elaborate theoretical work in offices and conference rooms, using computer simulations and spreadsheets, in the hope of determining fundamental mechanisms. They typically focus on creating big projects that promise to yield "silver bullet" solutions. While this approach can certainly have its rewards, it's not the Toyota way.

TPS constitutes a highly empirical method of managing a multistep manufacturing process. Such empiricism beats simulation, because no simulation model is sophisticated enough to capture the complexities inherent in semiconductor processing. The fastest way to develop process understanding is to execute lots of small, fast-paced scientific experiments on the factory floor. The factory is the laboratory. This is the essence of TPS—rapid, iterative, experimental problem solving.

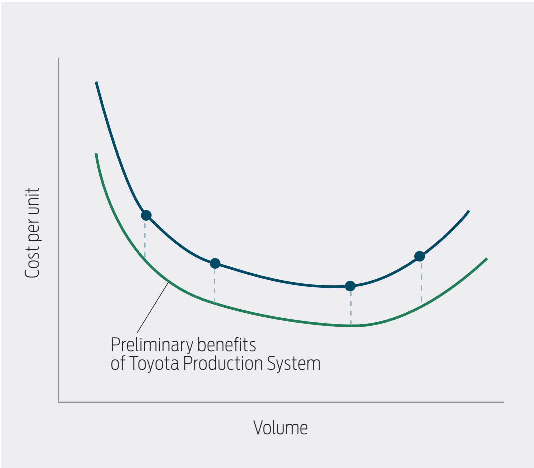
Such experimentation, done in the course of regular production work on the factory floor, doesn't necessarily yield a final, perfect answer to a particular problem—no such perfection may exist. Nor does TPS use an off-the-shelf "cookbook" approach. Instead it adjusts to the strategic imperatives concerning cost, quality, flexibility, or any other metric the company wishes to emphasize at a given time. For this project, our client instructed us to concentrate on reducing cycle time and cost, both of which were critical to opening new markets for the fab.

THE TOYOTA PRODUCTION SYSTEM SANITY CHECK

Many semiconductor companies have instituted "lean" manufacturing. Perhaps you are already following the Toyota Production System without knowing it. Try taking the TPS test. Be sure to ask a few different fab people these questions. You may get some very different answers.

Questions

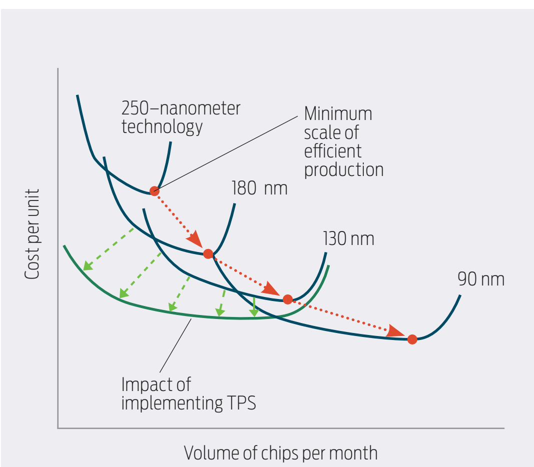
1. Do you know the theoretical minimum time to process a wafer?
2. Do you know exactly how many process steps are required to complete a wafer?
3. Is your actual manufacturing process time less than twice your theoretical minimum process time?
   a. Do you know the critical process step that constrains the throughput capacity of your fab?
   b. Is the uptime of the process equipment in that step predictable?
   c. Is there a fundamental reason that the manufacturing process time cannot approach the theoretical minimum process time in your fab?
4. Do you know the cost per wafer of each process step?
   a. Is your scrap rate less than 2 percent?
   b. Is your rework rate less than 2 percent?
5. Do you know exactly how many wafers are in your fab?
   a. How many are product wafers?
   b. How many are test wafers or process-monitor wafers?
   c. How many are engineering wafers?
   d. What is the ratio of product-wafer processing to non-product-wafer processing?
6. Were you able to rapidly identify and trace the latest drop in yield in your fab?
   a. Did you have enough data to empirically correlate the yield drop to a piece of equipment or specific process step?
   b. How do you know that the process equipment is operating within specifications?
7. Did everyone give you the same answers? Were they all in the fab today?



TPS Lowers the Curve

THE TOYOTA PRODUCTION SYSTEM both lowers cost per unit and reduces the volume necessary to minimize cost per unit. The result: new opportunities for growth and profitability.

SOURCE: CLAYTON M. CHRISTENSEN, STEVEN KING, MATT VERLINDEN & WOODWARD YANG



New Opportunities For Profitable Growth

THE FULL IMPACT of Moore's Law on the semiconductor industry is illustrated by the red line, which shows how the cost per unit falls, but only at ever-rising manufacturing volumes. In contrast, TPS not only lowers the minimum cost but also changes the shape of the curve, making it possible to produce at low cost and at low volume. This is the new economics of semiconductor manufacturing.

SOURCE: CLAYTON M. CHRISTENSEN, STEVEN KING, MATT VERLINDEN & WOODWARD YANG

In January 2007, we set to work on this collaborative effort. At its inception, the organization viewed the initiative to implement TPS as just another management flavor of the month. The prevailing attitude was to wait it out until the consultants left and things returned to normal. Thanks to the commitment, tenacity, and vision of the plant manager, this kind of resistance melted away.

To get the people at the fab to buy into our program, we formed a project team composed of eight people representing key functions, such as manufacturing management, equipment maintenance, finance, strategic planning, engineering, and fab floor personnel. As the first item of business, the team set a goal to cut costs by 12 percent and cycle time by 32 percent within the first six months. Moreover, we strove to build a learning organization that would be able to sustain the work long after we had left.

The next order of business was to train people in the Toyota system and in manufacturing science. In accordance with Toyota's principles, much of the training took place on the fab floor. The plant management played the role of new hires attempting to gain certification to process wafers in the fab under the supervision of a senior technician. In other words, they acted as apprentices. The basic premise behind this approach is that in order to mentor, coach, or teach someone to solve problems, you must have direct experience in solving them yourself.

Although at first this learning technique met with considerable resistance (and skepticism), it proved to be highly effective. Many members of the plant's management were very surprised, and exhausted, after experiencing what a typical day was really like for the people who actually make the product.

By August 2007, the organization had lowered cycle time in the fab by 67 percent and reduced costs by 12 percent. In addition, the number of products produced increased by 50 percent, and the production capacity increased by 10 percent, all without additional investment. If the fab continues on this journey of organizational learning and improves aspects such as equipment maintenance variability, we expect even bigger gains.

THE POTENTIAL IMPACT of the Toyota Production System is profound, because its improvements affect the general relationship between a factory's cost of additional production capacity and the average cost per unit. This relationship forms what economists call an economy-of-scale curve, and it applies to a number of capital-intensive businesses, including semiconductor and automobile manufacturing.

Let's examine the concept in detail. Imagine that it costs an average of $20 per chip to produce 2000 identical chips. If you then increase the volume to 4000 chips, the average unit cost drops to $12 per chip. Increase it further, say, to 6000 chips, and the cost per chip will drop to $10. This is a consequence of many factors, but mostly the rise in operational efficiency and manufacturing yields.

The major reason for increasing the size of a plant is to make full use of the lower unit cost that can be achieved at higher production volume, that is, economies of scale. Economies of scale exist when the factory's total capital and operating costs are increasing at a slower rate than its production volume.

Remember the old adage "You can't get something for nothing"? Well, there comes a point when you can't increase the output without making costs rise at an even faster rate. To take our earlier example, if you increase your output to 7000, the result may be that the cost per chip rises to $11. Increase the volume to 8000 and the cost per unit rises to $16 per chip. This rise comes because layers of management tend to grow as the workforce grows and because the burden of management increases as additional product types are assigned. Such "diseconomies of scale" explain the right-hand side of the U-shaped scale-to-cost curve [see graph, "TPS Lowers the Curve"].

Implementing TPS not only reduces the cost per unit at a given production volume, it also reduces the minimum number of units a

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

fab needs to turn out to be cost-effective. That is, TPS moves the cost curve down and also broadens it.

Throughout the past 40 years, the only way to move the scale curve has been through the pursuit of Moore's Law, along with the enormous capital investment that this entails. Unfortunately, such spending pushes the curve not only down but also to the right [see graph, "New Opportunities for Profitable Growth"]. The result has been an increase in the minimum volume at which production is cost-effective. What all this means is that TPS will lower both the minimum cost and the volume of efficient production. When that happens, a lot of the great engineering ideas that have been shot down by the bean counters over the years will suddenly become attractive from a business perspective.

THE NEW ECONOMICS of semiconductor manufacturing now makes it possible to produce chips profitably in much smaller volumes. This effect may not be very important for the fabs that make huge numbers of high-performance chips, but then again, that segment will take up a declining share of the total market. This isn't because demand for those chips will shrink. Rather, demand will grow even faster for products that require chips with rapid time-to-market and lower costs, such as consumer electronics.

Competition is shifting toward a new playing field. Now what matters is making a large variety of products, each product in small volumes and each perhaps for only a short time. Examples of these growing markets include cellphones and MP3 players, which are subject to trends in fashion. Then there are the thousands of chips that are increasingly finding their way into our homes, offices, automobiles—and into every nook and cranny of our lives.

YOU OFTEN HEAR executives in the semiconductor industry sighing for the next great vehicle for industry growth, like the PC in the 1990s and the minicomputer before that. Well, perhaps the next killer application won't be one thing but rather scores or hundreds of things, none of which require the raw performance that only the biggest, most technically advanced fabs can provide. Perhaps what the next wave of killer apps requires is a new business model, made possible by such things as TPS.

Throughout history, business models that reduced the minimum effective size of factories have transformed entire industries. Steelmaking was transformed by the minimill's ability to efficiently produce small batches of steel, business computing by a succession of ever-smaller machines starting from mainframes for payrolls and ultimately leading to the personal computer, and photographic film processing by fully automated one-hour film-processing machines, which were then replaced by digital photography. Because these transformations offered customers entirely new ways of doing things—rather than simply making the existing model work a bit better—we call them disruptions. The agents of disruption are invariably business models (although these models often come with a new technology wrapped inside).

Toyota's system has transformed the automobile industry. Fifty years ago, the industry offered far fewer car models because its scale curve was high—you had to sell a lot of units of a given model to be cost-effective. For example, in the 1950s, Chevrolet sold 1.5 million Impalas per year, a number that was considered high but not extraordinary. Now the industry regards 250 000 units per year as high, and many models sell at only a fifth to a tenth of that rate.

This change came about because of the decline in the minimum economic scale of a car factory. Some companies have handled the transition better than others. GM, once the paragon of massive mass production, posted a record $39 billion loss for 2007, providing yet more evidence of how hard it can be to emulate Toyota.

But there's more. To gain full benefit from the advances made on the manufacturing side, you may also need to restructure product development and design, purchasing, marketing, service, and other aspects of your company. That is, you must create a new business model.

Consider how the emergence of standardized modular components has made it possible for a technically untrained person to select among them and order a precisely configured computer, which a company can assemble and deliver in three days. This business model, made famous by Dell, has created new markets, industries, and subindustries.

Now imagine this modular design idea being extended to semiconductor devices. If that happened, even MBAs might be capable of specifying the components of their very own chips to be delivered to their doorsteps. Well, maybe not MBAs, but you get the picture. ❑

TO PROBE FURTHER Learn more about factory management science and the Toyota Production System at http://spectrum.ieee.org/may08/chipecon.

THE FOOTHILLS of the Rocky Mountains are as good a place as any to go green. The Sawyer family's Prius plug-in hybrid can now draw cheaper, cleaner electrical power.

PLUGGING AW

JONATHAN SAWYER SPENT $30 000—AND VOIDED THE WARRANTY—TO

/AY IN A PRIUS

ADD A PLUG TO HIS PRIUS HYBRID *By John Voelcker* *Photography by Ray Ng*

TEN YEARS AGO, JONATHAN SAWYER wanted an all-electric car badly enough to lease a General Motors EV1 from his sister's address in Arizona, one of the few states where GM marketed the car. He smuggled it into his hometown of Boulder, Colo., on the back of a flatbed, and periodically returned it to Tempe, Ariz., for maintenance the same way—until his dealer refused to service it, noting that his radio presets weren't local, the car's garage-door opener was useless in his sister's carport, and a photo of his EV1 had appeared in a Boulder newspaper.

Later, relations with GM improved; Sawyer even got the company to lease him two more EV1s in Colorado when Arizona demand proved low. But that low demand gave him an insight: if even environmentalists in Boulder weren't going for EV1s, what hope did the car have in the mass market? GM was probably right, he reluctantly concluded, when the company apparently decided in 2003 that the market wasn't ready for a two-seater with a 110-kilometer (70-mile) range and an 8-hour recharge time.

Now Sawyer is one of the first people in the world to own a car conceived and designed precisely to overcome the range problem: a plug-in hybrid electric vehicle, or PHEV. An electrical engineer by training and cofounder of FreeWave Technologies, a start-up that makes radio-telemetry equipment, Sawyer has pursued new and alternative technologies for years. His house has both photovoltaic panels and a wind turbine. Before the PHEV, his main ride about town was an all-electric Toyota RAV4 EV. So last year, the 52-year-old single father of two school-age daughters (Allison, 12, and Melanie, 10) opted for the state of the art in automotive environmentalism.

In October, Sawyer paid US $25 000 for a brand-new black 2008 Toyota Prius. But compared with his RAV4 EV, it was a gas guzzler, going only 1 or 2 km electrically before switching on its internal combustion engine. So Sawyer wrote a check for the car, then drove it directly to Hybrids Plus, also in Boulder, where he wrote another check, for $32 000—to have his shiny new Prius converted into a PHEV. (The radio-telemetry business has been very good to Sawyer.)

A plug-in conversion service either replaces the car's original battery pack with one having far higher energy capacity, as Hybrids Plus does, or supplements it, as many other conversion companies do. The car can then travel, in this case, up to 50 km in all-electric mode without switching on the engine. The conversion also adds a charging system that lets an owner recharge that pack by plugging into a standard household electrical outlet.

For trips beyond the 50-km pure-EV range, the vehicle carries its own recharging system—the car's original gas-powered engine. The converted car consumes much less fuel than a standard hybrid. A PHEV's mileage varies with differing driving styles and geography, but plug-in owners like to quote figures like 3.4 to 2.9 liters per 100 km (70 to 80 miles per gallon). PHEVs running in electric mode cost far less to operate—at a typical cost for nighttime grid electricity, roughly $0.02 per mile, against roughly $0.14 per mile for gasoline-fueled travel.

SOMEDAY, MILLIONS OF CARS will come off assembly lines as plug-in hybrids. Analysts are mostly agreed on that. But for now, in the whole wide world fewer than 200 PHEVs roam the roads. Plug-in conversions are a cottage industry in North America, offered in kit or turnkey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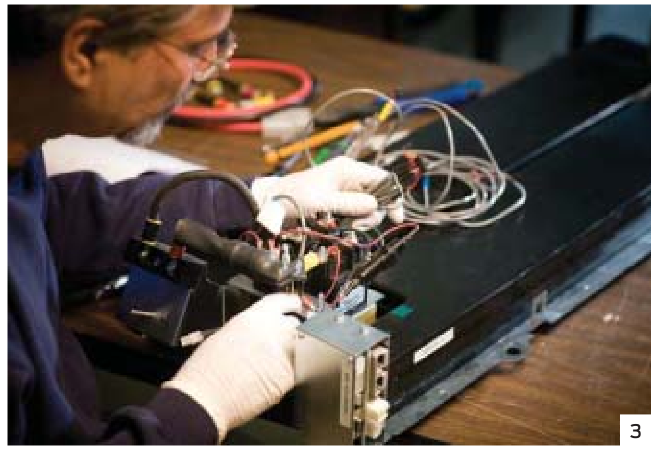

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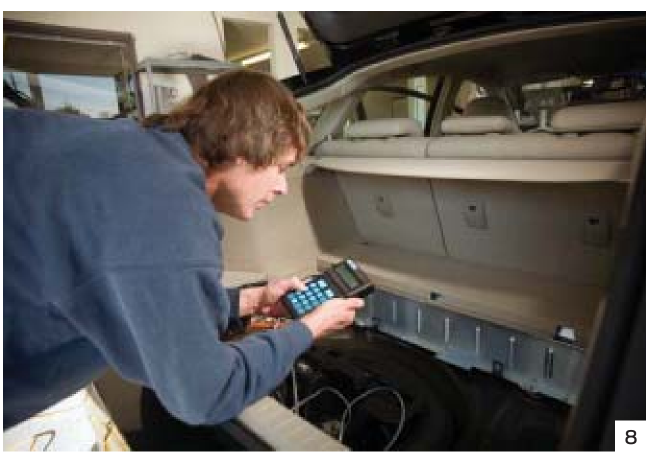

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Getting on the Grid

ENTERING THE HYBRIDS PLUS SHOP, the Sawyer car was just another black Prius **[1]**. Even before the car arrived, the shop's technicians began assembling the replacement battery pack, including roughly 600 Chinese-made lithium-ion cells (each 26 millimeters in diameter by 650 mm long) **[2]**, sold by A123 Systems of Watertown, Mass., and a battery controller, which monitors the performance of each individual cell, manages power output, and keeps the pack within operating limits. Here **[3]**, a Hybrids Plus engineer wires the controller into the pack's internal harness.

Next, the interior of the car's cargo area is stripped of trim **[4]** and the original Panasonic 1.3-kilowatt-hour nickel-metal-hydride (NiMH) pack removed **[5]**. With the old battery out **[6]**, the 4.5-kWh replacement pack built by Hybrids Plus can be lowered into place **[7]** and mounted securely, then wired into the car's high-voltage and 12-volt harnesses and its internal communications system. Because lithium-ion cells have roughly twice the energy density of NiMH cells, the larger replacement pack more than triples the energy capacity while adding less than 15 kilograms to the Prius's original weight of about 1310 kg. The optional extension pack adds 40 kg more.

With the replacement pack in place and the seats refitted, the pack's electrical performance is tested **[8]**. The rest of the cargo-area interior can then be reinstalled **[9]**. Before the first road test, there's one final task: connecting a standard three-prong heavy-duty extension cord to the carefully hidden plug and charging up the battery **[10]**! The plug for external charging is actually one of the car's neater features, located within a special light fitting that replaces one of the two standard Prius license-plate lights. Its cables run through the same plastic tube as the rest of the tailgate wiring. After conversion, the only indications of the car's PHEV status on the Sawyers' Prius are some added instrumentation and a couple of dash buttons, the plug itself, and a slightly less spacious cargo area. Unless you hear it go by, of course—or rather don't hear it, because it's running quietly, just on electricity.

EMBARRASSMENT OF RICHES: Over the course of two years, the photovoltaic cells on the Sawyers' house have generated 2000 kilowatt-hours more than the family used; they sold the excess to their utility.

form by perhaps a dozen businesses and organizations. Over the past two years, the budding industry has been aided and abetted by a remarkable and vocal network of plug-in owners, advocates, and fans. They swamp Internet bulletin boards and e-mail their government representatives, arguing for a vast R&D effort aimed at producing cars that get 100 miles per gallon or more, powered as much as possible by grid electricity. The key enabler is recent advances in large-format lithium-ion batteries [see "Lithium Batteries Take to the Road," *IEEE Spectrum*, September 2007].

One influential advocacy group is the California Cars Initiative, a Palo Alto–based nonprofit start-up of entrepreneurs, engineers, environmentalists, and consumers. CalCars maintains a popular wiki on all topics having to do with plug-in hybrids, particularly public policy and technology developments (http://www.calcars.org). By stirring demand, the organization hopes to "encourage automakers to produce 100+ MPG 'no-sacrifices' high-performance, clean hybrid cars," to quote its mission statement. Or as Carl Lawrence, lead founder and CEO of converter Hybrids Plus, says, "It's about creating the perception that this can be done—that if you're not talking 60 or 80 miles per gallon, then you're wasting your time."

It's quite a big tent of proponents, with some of them worried more about national security than ecology. R. James Woolsey Jr., former director of the CIA, told an IEEE symposium last fall that he views plug-ins as one way to help "destroy oil as a strategic commodity."

Right now, though, if you want a plug-in, converting an existing conventional hybrid-electric vehicle is the only way to go. It will be three years or more before any of the major automakers sells a car designed from the ground up as a PHEV. Even then, the industry will most likely have to subsidize the cost of the battery packs for years. It's widely assumed that Toyota has subsidized its hybrid vehicles, which make up almost 80 percent of the hybrids sold worldwide since the first-generation Prius was introduced in 1997.

THE SECOND-GENERATION PRIUS, introduced in 2003, is the highest-volume hybrid vehicle ever made. Toyota has now built more than half a million of them. Last year, the company sold 181 221 Priuses in the United States alone; the model's distinctive wedge profile suggests "hybrid car" the same way the distinctive radiator shell of a Rolls-Royce intones "luxury." The Prius also makes a surprisingly good PHEV, considering that it was never intended to be one. And to explain why, we'll start by tearing apart a stock Prius.

Toyota's Hybrid Synergy Drive system seamlessly shuffles power among the combustion engine, two electric motor-generators, and a battery pack. The main 50-kilowatt (67-horsepower) motor-generator does just one thing: it drives the front wheels through a reduction gear, which reduces the motor-generator's rotational speed to the wheels' lower speed. The secondary motor-generator serves several mas-

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

ters. It recharges the 1.3-kilowatt-hour nickel-metal-hydride (NiMH) battery pack, and it supplements the power from the main electric motor when more propulsion is needed. The secondary motor-generator also quickly starts the gas engine. To save fuel, the Prius, like most conventional hybrids, shuts off its gasoline engine whenever the car is not in motion—for example, at a stoplight—and then restarts it when the car gets back up to about 25 km/h or whenever the driver steps down hard on the accelerator.

The mechanism by which the system shuffles power, and the heart of Hybrid Synergy Drive, is known as a planetary gear set. In this set, a central gear (the "sun") connects to the drive shaft of the secondary motor-generator. Its "planet" gears are in turn surrounded by a ring gear that drives, or is driven by, the main motor-generator—which is also connected to the differential that turns the wheels. The carrier for the planet gears is connected to the engine's output shaft.

By varying the speed at which the planet gears spin, this arrangement allows the system's control software to alter the power split between primary and secondary motor-generators. More speed means more power going to the main motor. All three components—the ring gear, the planetary carrier, and the sun gear—work in unison to control the torque output through the ring gear to the wheels.

In a Prius, then, engine power may either turn the wheels or recharge the battery pack. The car's control software makes those decisions, splitting motive power between engine and electric motors, recharging, and regenerating power on braking.

Depending on driving needs, the primary electric motor can provide up to 78 percent of the car's total torque of 515 newton meters (380 foot-pounds) or spin the shaft of the secondary motor to recharge the batteries. The system adjusts relative power levels without changing the mechanical load on the engine. The driver needs only to brake and accelerate; software makes all the necessary decisions. Unless a driver pays close attention to the graphic shown on the car's dashboard display, it's possible to drive a Prius without ever knowing it's a hybrid—though it's occasionally *very* quiet for a car.

Under certain driving conditions, an unmodified Prius can run as fast as 65 km/h (40 mph) on electric power alone, but only for a kilometer or two. Priuses sold in Europe and Japan (but not in the United States) have an "EV Mode" switch on the dashboard. It commands the car to power itself purely on electricity for a short period, drawing more energy from the batteries than the car's power-shifting algorithms would otherwise permit. Its all-electric range, however, is 1 to 2 km at most at neighborhood speeds. The EV-mode switch was removed for the U.S. market, by the way, because cars sold there must guarantee that all elements of their emissions-control systems will function properly without maintenance for 10 years or 220 000 km, whichever comes first. Using the EV-mode switch increases the demand on the stock Prius's NiMH batteries and in so doing makes the U.S.-market lifetime requirements more of a stretch.

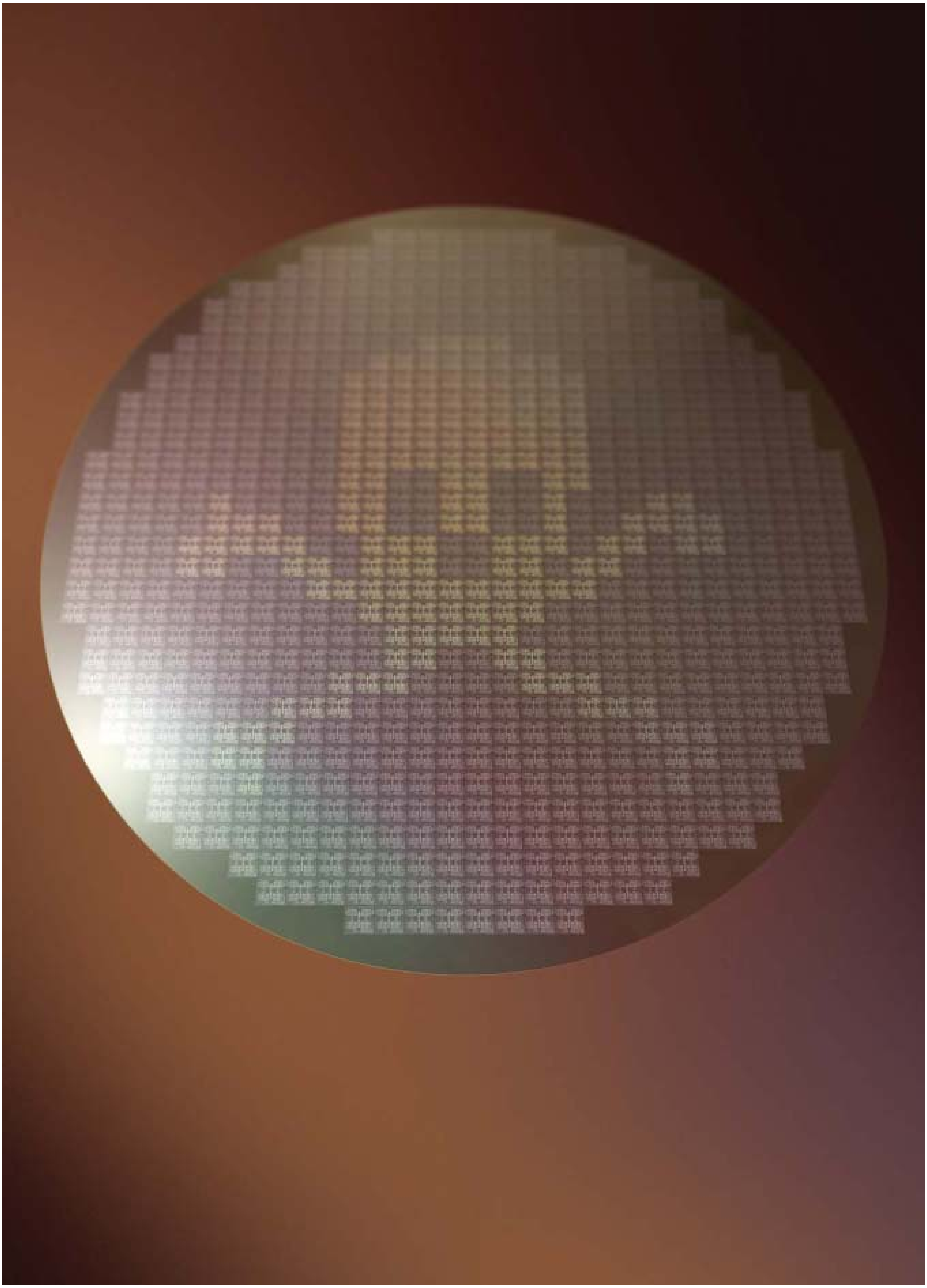
To maximize the chances that the standard Prius battery pack will survive 10 years under any conceivable operating conditions, Toyota rigorously keeps the pack's state of charge—expressed as a percentage of the full-capacity charge—between 50 and 80 percent. Toyota does not disclose exact details, but some engineers say the band is even narrower under most operating circumstances.

Hybrids Plus replaced the original 1.3-kWh NiMH battery pack in Sawyer's new Prius with a custom-built 4.5-kWh pack. The new pack, which fits inside the exact same opening in the trunk floor that the old pack did, turns the car into a PHEV-15, the number indicating its all-electric range of 15 miles (24 km). But like most of the company's 10 Prius customers to date, Sawyer opted for an extension pack with another 4.5 kWh, making the car a PHEV-30. That secondary pack, which is mounted unobtrusively under the cargo-area carpeting, occupies roughly 45 liters (less than 2 cubic feet) of space. While it reduces load space somewhat, that's the tradeoff for 24 more electric kilometers.

HOW DO YOU MORE THAN TRIPLE the capacity of a battery pack without greatly altering its volume? In this case, you go from nickel-metal-hydride to lithium-ion. The 4.5-kWh battery pack contains roughly 600 lithium-ion cells manufactured in China by A123 Systems of Watertown, Mass. A123 says that its cells, which use lithium-ion nanophosphate for the cathode, will retain much of their energy capacity over 10 years, performing far better than the cobalt-oxide chemistries used in mobile phones and laptops. Laptop batteries generally last fewer than five years before their ability to recharge has declined enough—40 or 50 percent, say—to require replacement. A123's cells were designed to do much better, but the company's oldest cells—for power tools— *Continued on page 42*

THE SUBTLE DIFFERENCE: You'd never realize this Prius was a plug-in unless you knew where to find the 110-volt plug: built neatly into the right-hand license-plate light.

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags



JAMES ARCHER/ANATOMYBLUE

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

THE HUNT FOR THE KILL SWITCH

ARE CHIP MAKERS BUILDING ELECTRONIC TRAPDOORS IN KEY MILITARY HARDWARE? THE PENTAGON IS MAKING ITS BIGGEST EFFORT YET TO FIND OUT *BY SALLY ADEE*

LAST SEPTEMBER, Israeli jets bombed a suspected nuclear installation in northeastern Syria. Among the many mysteries still surrounding that strike was the failure of a Syrian radar—supposedly state-of-the-art—to warn the Syrian military of the incoming assault. It wasn't long before military and technology bloggers concluded that this was an incident of electronic warfare—and not just any kind.

Post after post speculated that the commercial off-the-shelf microprocessors in the Syrian radar might have been purposely fabricated with a hidden "backdoor" inside. By sending a preprogrammed code to those chips, an unknown antagonist had disrupted the chips' function and temporarily blocked the radar.

That same basic scenario is cropping up more frequently lately, and not just in the Middle East, where conspiracy theories abound. According to a U.S. defense contractor who spoke on condition of anonymity, a "European chip maker" recently built into its microprocessors a kill switch that could be accessed remotely. French defense contractors have used the chips in military equipment, the contractor told *IEEE Spectrum*. If in the future the equipment fell into hostile hands, "the French wanted a way to disable that circuit," he said. *Spectrum* could not confirm this account independently, but spirited discussion about it among researchers and another defense contractor last summer at a military research conference reveals a lot about the fever dreams plaguing the U.S. Department of Defense (DOD).

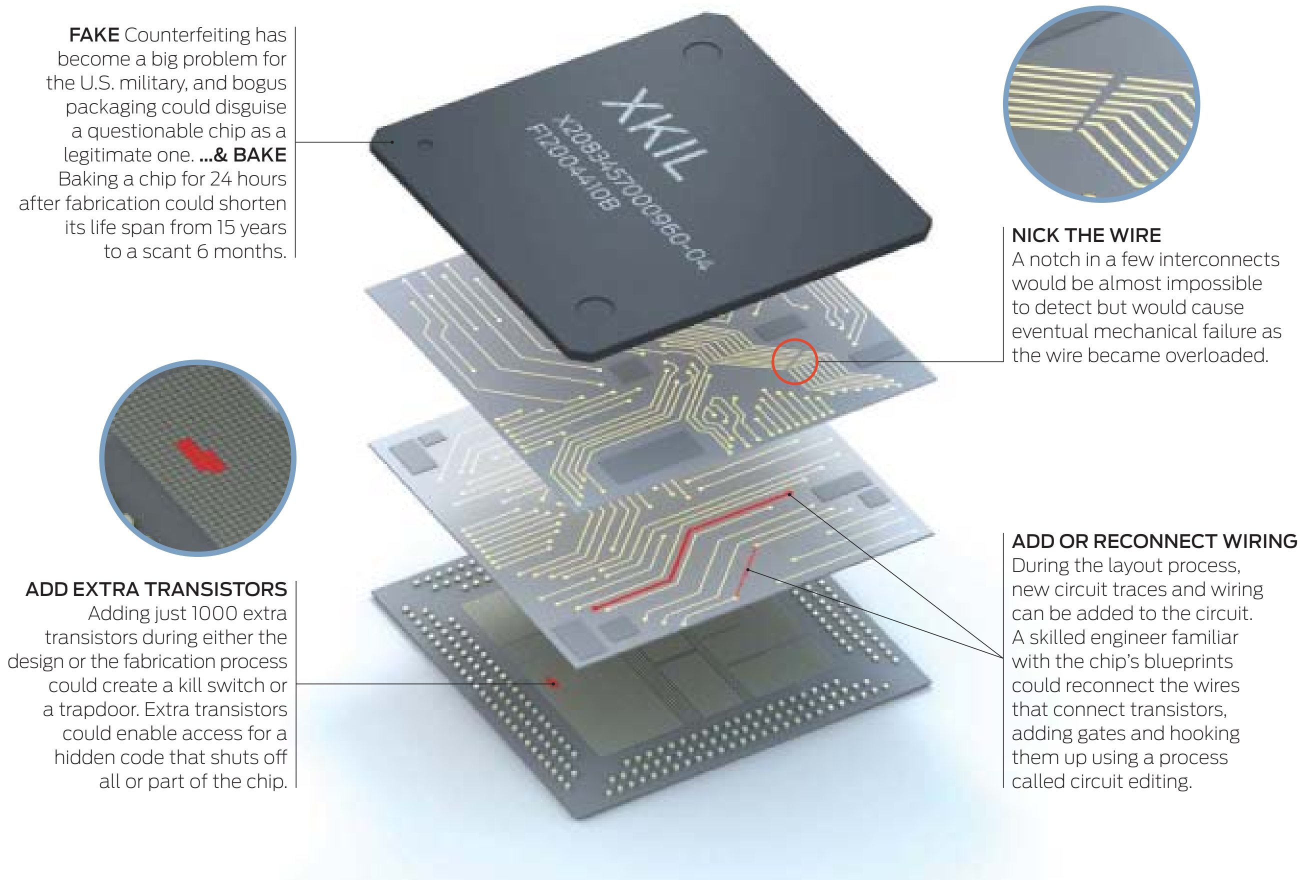
Feeding those dreams is the Pentagon's realization that it no longer controls who manufactures the components that go into its increasingly complex systems. A single plane like the DOD's next generation F-35 Joint Strike Fighter, can contain an "insane number" of chips, says one semiconductor expert familiar with that aircraft's design. Estimates from other sources put the total at several hundred to more than a thousand. And tracing a part back to its source is not always straightforward. The dwindling of domestic chip and electronics manufacturing in the United States, combined with the phenomenal growth of suppliers in countries like China, has only deepened the U.S. military's concern.

Recognizing this enormous vulnerability, the DOD recently launched its most ambitious program yet to verify

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

RECIPE FOR DISASTER

AT EACH step of the hardware design process, a saboteur could make a particular part of the circuit fail. A typical microprocessor can have up to eight layers, and any layer on a microchip can be targeted. ILLUSTRATION: EMILY COOPER



the integrity of the electronics that will underpin future additions to its arsenal. In December, the Defense Advanced Research Projects Agency (DARPA), the Pentagon's R&D wing, released details about a three-year initiative it calls the Trust in Integrated Circuits program. The findings from the program could give the military—and defense contractors who make sensitive microelectronics like the weapons systems for the F-35—a guaranteed method of determining whether their chips have been compromised. In January, the Trust program started its prequalifying rounds by sending to three contractors four identical versions of a chip that contained unspecified malicious circuitry. The teams have until the end of this month to ferret out as many of the devious insertions as they can.

Vetting a chip with a hidden agenda can't be all that tough, right? Wrong. Although commercial chip makers routinely and exhaustively test chips with hundreds of millions of logic gates, they can't afford to inspect everything. So instead they focus on how well the chip performs specific functions. For a microprocessor destined for use in a cellphone, for instance, the chip maker will check to see whether all the phone's various functions work. Any extraneous circuitry that doesn't interfere with the chip's normal functions won't show up in these tests.

"You don't check for the infinite possible things that are not specified," says electrical engineering professor Ruby Lee, a cryptography expert at Princeton. "You could check the obvious possibilities, but can you test for every unspecified function?"

Nor can chip makers afford to test every chip. From a batch of thousands, technicians select a single chip for physical inspection, assuming that the manufacturing process has yielded essentially identical devices. They then laboriously grind away a thin layer of the chip, put the chip into a scanning electron microscope, and then take a picture of it, repeating the process until every layer of the chip has been imaged. Even here, spotting a tiny discrepancy amid a chip's many layers and millions or billions of transistors is a fantastically difficult task, and the chip is destroyed in the process.

But the military can't really work that way. For ICs destined for mission-critical systems, you'd ideally want to test every chip without destroying it.

The upshot is that the Trust program's challenge is enormous. "We can all do with more verification," says Samsung's Victoria Coleman, who helped create the Cyber Trust initiative to secure congressional support for cybersecurity. "My advice to [DARPA director] Tony Tether was 'trust but verify.' That's all you can do."

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

Semiconductor offshoring dates back to the 1960s, when U.S. chip makers began moving the labor-intensive assembly and testing stages to Singapore, Taiwan, and other countries with educated workforces and relatively inexpensive labor.

Today only Intel and a few other companies still design and manufacture all their own chips in their own fabrication plants. Other chip designers—including LSI Corp. and most recently Sony—have gone "fabless," outsourcing their manufacturing to offshore facilities known as foundries. In doing so, they avoid the huge expense of building a state-of-the-art fab, which in 2007 cost as much as US $2 billion to $4 billion.

Well into the 1970s, the U.S. military's status as one of the largest consumers of integrated circuits gave it some control over the industry's production and manufacturing, so the offshoring trend didn't pose a big problem. The Pentagon could always find a domestic fab and pay a little more to make highly classified and mission-critical chips. The DOD also maintained its own chip-making plant at Fort Meade, near Washington, D.C., until the early 1980s, when costs became prohibitive.

But these days, the U.S. military consumes only about 1 percent of the world's integrated circuits. "Now," says Coleman, "all they can do is buy stuff." Nearly every military system today contains some commercial hardware. It's a pretty sure bet that the National Security Agency doesn't fabricate its encryption chips in China. But no entity, no matter how well funded, can afford to manufacture its own safe version of every chip in every piece of equipment.

The Pentagon is now caught in a bind. It likes the cheap, cutting-edge devices emerging from commercial foundries and the regular leaps in IC performance the commercial sector is known for. But with those improvements comes the potential for sabotage. "The economy is globalized, but defense is not globalized," says Coleman. "How do you reconcile the two?"

In 2004, the Defense Department created the Trusted Foundries Program to try to ensure an unbroken supply of secure microchips for the government. DOD inspectors have now certified certain commercial chip plants, such as IBM's Burlington, Vt., facility, as trusted foundries. These plants are then contracted to supply a set number of chips to the Pentagon each year. But Coleman argues that the program blesses a process, not a product. And, she says, the Defense Department's assumption that onshore assembly is more secure than offshore reveals a blind spot. "Why can't people put something bad into the chips made right here?" she says.

Three years ago, the prestigious Defense Science Board, which advises the DOD on science and technology developments, warned in a report that the continuing shift to overseas chip fabrication would expose the Pentagon's most mission-critical integrated circuits to sabotage. The board was especially alarmed that no existing tests could detect such compromised chips, which led to the formation of the DARPA Trust in IC program.

Where might such an attack originate? U.S. officials invariably mention China and Russia. Kenneth Flamm, a technology expert at the Pentagon during the Clinton administration who is now a professor at the University of Texas at Austin, wouldn't get that specific but did offer some clues. Each year, secure government computer networks weather thousands of attacks over the Internet. "Some of that probing has come from places where a lot of our electronics are being manufactured," Flamm says. "And if you're a responsible defense person, you would be stupid not to look at some of the stuff they're assembling, to see how else they might try to enter the network."

John Randall, a semiconductor expert at Zyvex Corp., in Richardson, Texas, elaborates that any malefactor who can penetrate government security can find out what chips are being ordered by the Defense Department and then target them for sabotage. "If they can access the chip designs and add the modifications," Randall says, "then the chips could be manufactured correctly anywhere and still contain the unwanted circuitry."

So what's the best way to kill a chip? No one agrees on the most likely scenario, and in fact, there seem to be as many potential avenues of attack as there are people working on the problem. But the threats most often mentioned fall into two categories: a kill switch or a backdoor.

A kill switch is any manipulation of the chip's software or hardware that would cause the chip to die outright—to shut off an F-35's missile-launching electronics, for example. A backdoor, by contrast, lets outsiders gain access to the system through code or hardware to disable or enable a specific function. Because this method works without shutting down the whole chip, users remain unaware of the intrusion. An enemy could use it to bypass battlefield radio encryption, for instance.

Depending on the adversary's degree of sophistication, a kill switch might be controlled to go off at a set time, under certain circumstances, or at random. As an example of the latter, Stanford electrical engineering professor Fabian Pease muses, "I'd nick the [chip's] copper wiring." The fault, almost impossible to detect, would make the chip fail early, due to electromigration: as current flowed through the wire, eventually the metal atoms would migrate and form voids, and the wire would break. "If the chip goes into a defense satellite, where it's supposed to work for 15 years but fails after six months, you have a very expensive, inoperative satellite," Pease says.

But other experts counter that such ideas ignore economic realities. "First and foremost, [the foundries] want to make sure their chips work," says Coleman. "If a company develops a reputation for making chips that fail early, that company suffers more than anyone else."

A kill switch built to be triggered at will, as was allegedly incorporated into the European microprocessors, would be more difficult and expensive to pull off, but it's also the more likely threat, says David Adler, a consulting professor of electrical engineering at Stanford, who was previously funded by DARPA to develop chip-testing hardware in an unrelated project.

To create a controlled kill switch, you'd need to add extra logic to a microprocessor, which you could do either during manufacturing or during the chip's design phase. A saboteur could substitute one of the masks used to imprint the pattern of wires and transistors onto the semiconductor wafer, Adler suggests, so that the pattern for just one microchip is different from the rest. "You're printing pictures from a negative," he says. "If you change the mask, you can add extra transistors."

Or the extra circuits could be added to the design itself. Chip circuitry these days tends to be created in software modules, which can come from anywhere, notes Dean Collins, deputy director of DARPA's Microsystems Technology Office and program manager for the Trust in IC initiative. Programmers "browse many sources on the Internet for a component," he says. "They'll find a good one made by somebody in Romania, and they'll put that in their design." Up to two dozen different software tools may be used to design the chip, and the origin of that software is not always clear, he adds. "That creates two dozen entry points for malicious code."

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

Collins notes that many defense contractors rely heavily on field-programmable gate arrays (FPGAs)—a kind of generic chip that can be customized through software. While a ready-made FPGA can be bought for $500, an application-specific IC, or ASIC, can cost anywhere from $4 million to $50 million. "If you make a mistake on an FPGA, hey, you just reprogram it," says Collins. "That's the good news. The bad news is that if you put the FPGA in a military system, someone else can reprogram it."

Almost all FPGAs are now made at foundries outside the United States, about 80 percent of them in Taiwan. Defense contractors have no good way of guaranteeing that these economical chips haven't been tampered with. Building a kill switch into an FPGA could mean embedding as few as 1000 transistors within its many hundreds of millions. "You could do a lot of very interesting things with those extra transistors," Collins says.

The rogue additions would be nearly impossible to spot. Say those 1000 transistors are programmed to respond to a specific 512-bit sequence of numbers. To discover the code using software testing, you might have to cycle through every possible numerical combination of 512-bit sequences. That's 13.4×10^{153} combinations. (For perspective, the universe has existed for about 4×10^{17} seconds.) And that's just for the 512-bit number—the actual number of bits in the code would almost certainly be unknown. So you'd have to apply the same calculations to all possible 1024-bit numbers, and maybe even 2048-bit numbers, says Tim Holman, a research associate professor of electrical engineering at Vanderbilt University, in Nashville. "There just isn't enough time in the universe."

Those extra transistors could create a kill switch or a backdoor in any chip, not just an FPGA. Holman sketches a possible scenario: suppose those added transistors find their way into a networking chip used in the routers connecting the computers in your home, your workplace, banks, and military bases with the Internet. The chip functions perfectly until it receives that 512-bit sequence, which could be transmitted from anywhere in the world. The sequence prompts the router to hang up. Thinking it was the usual kind of bug, tech support would reset the router, but on restart the chip would again immediately hang up, preventing the router from connecting to the outside world. Meanwhile, the same thing would be happening to similarly configured routers the world over.

The router scenario also illustrates that the nation's security and economic well-being depend on shoring up not just military chips but also commercial chips. An adversary who succeeded in embedding a kill switch in every commercial router could devastate national security without ever targeting the Defense Department directly.

A kill switch or backdoor built into an encryption chip could have even more disastrous consequences. Today encoding and decoding classified messages is done completely by integrated circuit—no more Enigma machine with its levers and wheels. Most advanced encryption schemes rely on the difficulty that computers have in factoring numbers containing hundreds of digits; discovering a 512-bit type of encryption would take some machines up to 149 million years. Encryption that uses the same code or key to encrypt and decrypt information—as is often true—could easily be compromised by a kill switch or a backdoor. No matter what precautions are taken at the programming level to safeguard that key, one extra block of transistors could undo any amount of cryptography, says John East, CEO of Actel Corp., in Mountain View, Calif., which supplies military FPGAs.

"Let's say I can make changes to an insecure FPGA's hardware," says East. "I could easily put a little timer into the circuit. The timer could be programmed with a single command: 'Three weeks after you get your configuration, forget it.' If the FPGA were to forget its configuration information, the entire security mechanism would be disabled."

Alternately, a kill switch might be programmed to simply shut down encryption chips in military radios; instead of scrambling the signals they transmit, the radios would send their messages in the clear, for anybody to pick up. "Just like we figured out how the Enigma machine worked in World War II," says Stanford's Adler, "one of our adversaries could in principle figure out how our electronic Enigma machines work and use that information to decode our classified communications."

Chip alteration can even be done after the device has been manufactured and packaged, provided the design data are available, notes Chad Rue, an engineer with FEI, based in Hillsboro, Ore., which makes specialized equipment for chip editing (albeit for legitimate reasons). FEI's circuit-editing tools have been around for 20 years, Rue says, and yet "chip designers are still surprised when they hear what they can do."

Skilled circuit editing requires electrical engineering know-how, the blueprints of the chip, and a $2 million refrigerator-size piece of equipment called a focused-ion-beam etching machine, or FIB. A FIB shoots a stream of ions at precise areas on the chip, mechanically milling away tiny amounts of material. FIB lab workers refer to the process as microsurgery, with the beam acting like a tiny scalpel. "You can remove material, cut a metal line, and make new connections," says Rue. The process can take from hours to several days. But the results can be astonishing: a knowledgeable technician can edit the chip's design just as easily as if he were taking "an eraser and a pencil to it," says Adler.

Semiconductor companies typically do circuit editing when they're designing and debugging prototypes. Designers can make changes to any level of the chip's wiring, not just the top. "It's not uncommon to dig through eight different layers to get to the intended target," says Rue. The only thing you can't do with a FIB is add extra transistors. "But we can reroute signals to the transistors that are already there," he says. That's significant because chips commonly contain large blocks of unused circuitry, leftovers from previous versions of the design. "They're just along for the ride," Rue says. He thinks it would be possible to use a FIB to rewire a chip to make use of these latent structures. To do so, an adversary would need a tremendous amount of skill with digital circuitry and access to the original design data. Some experts find the idea too impractical to worry about. But an adversary with unlimited funds and time—exactly what the Defense Science Board warned of—could potentially pull it off, Rue says.

In short, the potential for tinkering with an integrated circuit is almost limitless, notes Princeton's Lee. "The hardware design process has many steps," she says. "At each step, you could do something that would make a particular part of the IC fail."

Clearly, the companies participating in the Trust in IC program have their work cut out for them. As Collins sees it, the result has to be a completely new chip-verification method. He's divided up the Trust participants into teams: one group to create the test chips from scratch; another to come up with malicious insertions; three more groups, which

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

he calls "performers," to actually hunt for the errant circuits; and a final group to judge the results.

To fabricate the test chips, Collins chose the Information Sciences Institute at the University of Southern California, Los Angeles. He picked MIT's Lincoln Laboratory to engineer whatever sneaky insertions they could devise, and he tapped Johns Hopkins University Applied Physics Laboratory, in Laurel, Md., to come up with a way to compare and assess the performers' results.

The three performers are Raytheon, Luna Innovations, and Xradia. None of the teams would speak on the record, but their specialties offer some clues to their approach. Xradia, in Concord, Calif., builds nondestructive X-ray microscopes used widely in the semiconductor industry, so it may be looking at a new method of inspecting chips based on soft X-ray tomography, Stanford's Pease suggests. Soft X-rays are powerful enough to penetrate the chip but not strong enough to do irreversible damage.

Luna Innovations, in Roanoke, Va., specializes in creating anti-tamper features for FPGAs. Princeton's Lee suggests that Luna's approach may involve narrowing down the number of possible unspecified functions. "There are ways to determine where such hardware would be inserted," she says. "Where could they gather the most information? Where would they be least likely to be noticed? That is what they're looking for." She compares chip security to a barricaded home. The front door and windows might offer vault-like protection, but there might be an unknown window in the basement. The Luna researchers, she speculates, may be looking for the on-chip equivalent of the basement window.

Raytheon, of Waltham, Mass., has expertise in hardware and logic testing, says Collins. He believes the company will use a more complex version of a technique called Boolean equivalence checking to analyze what types of inputs will generate certain outputs. Normally, applying specific inputs to a circuit will result in specific, predictable outputs, just as hitting a light switch should always cause the light to turn off. "Now look at that process in reverse," says Collins. Given a certain output (the lights go out), engineers can reconstruct what made it happen (someone hit a switch). Collins says this could help avoid cycling through infinite combinations of inputs to find a single fatal response.

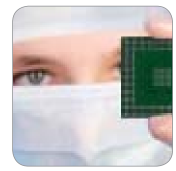
In January, the performers were given a set of four test chips, each containing an unknown (to them) number of malicious insertions. Along with a thorough description of the chips, Collins says, "we told them precisely what the circuits were supposed to be."

Each team's success will be gauged by the number of malicious insertions it can spot. The goal is a 90 percent detection rate, says Collins, with a minimum of false positives. The teams will also have to contend with red herrings: to trip them up, the test set includes fully functioning, uncompromised chips. By the end of this month, the performers will report back to DARPA. After Johns Hopkins has tallied the results, the teams will get a second set of test chips, which they'll have to analyze by the end of the year. Any performer that doesn't pass muster will be cut from the program, while the methods developed by the successful ones will be developed further. By the program's end in 2010, Collins hopes to have a scientifically verifiable method to categorically authenticate a circuit. "There's not going to be a DARPA seal of approval on them," says Collins, but both the Army and the Air Force have already expressed interest in adopting whatever technology emerges.

Meanwhile, other countries appear to be awakening to the chip threat. At a January hearing, a U.S. House Committee on Foreign Affairs addressed Pakistan's ongoing refusal to let the United States help it secure its nuclear arsenal with American technology. Pakistan remains reluctant to allow such intervention, citing fears that the United States would use the opportunity to cripple its weapons with—what else?—a kill switch. ❑

SCAVENGER HUNT

DARPA'S PROGRAM has formed teams to test chip integrity. USC's group creates the chips, which MIT's group then compromises with unknown additions. The "performers," Xradia, Luna Innovations, and Raytheon, are supposed to find the malicious alterations. And the Johns Hopkins group judges the results. The program's three phases get progressively harder, with the number of insertions increasing and the testing time decreasing.

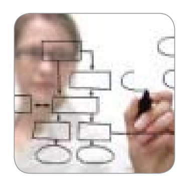


TEST-ARTICLE TEAM
USC Information Sciences Institute creates test chips.

RED TEAM
MIT Lincoln Labs inserts malicious circuits.

PERFORMER
Xradia studies X-ray analysis.

PERFORMER
Luna Innovations studies FPGAs.



PERFORMER
Raytheon studies design process, ASICs, and FPGAs.

METRICS TEAM
Johns Hopkins Applied Physics Lab develops ways to measure success.

ISTOCKPHOTO (6)

TO PROBE FURTHER For a comprehensive look into the failure of the Syrian radar, see "Cyber-Combat's First Shot," Aviation Week & Space Technology, *26 November 2007 by David A. Fulghum, Robert Wall, and Amy Butler. For more on the DARPA program and on the kill-switch debate, go to http://spectrum.ieee.org/may08/chiptrust.*

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

The man behind Moore's Law is tackling biodiversity, the future of engineering education, and the secrets of the galaxies

By Tekla S. Perry
Photography by joSon

GORDON MOORE'S NEXT ACT

MEDAL OF HONOR

GORDON E. MOORE, COFOUNDER AND CHAIRMAN emeritus of Intel Corp., the world's 288th richest man, and the eponymous soothsayer of one of technology's most famous "laws," sits across from me, eating a turkey sandwich.

He's been interviewed hundreds, maybe thousands of times by the likes of me. So I'm kind of at a loss for questions that won't bore him. "What would you like your legacy to the world to be?" I finally ask.

"Anything," he says, shaking his head ruefully, "but Moore's Law."

I don't have the heart to tell him how unlikely *that's* going to be. People who couldn't tell you exactly what DRAM does have heard of Moore's Law.

"ANYTHING BUT MOORE'S LAW": Semiconductor pioneer Gordon E. Moore hopes his philanthropic work will have an enduring impact.

Moore was a 36-year-old research physicist at Fairchild Semiconductor Corp. when he wrote his famous forecast, in the 35th anniversary issue of *Electronics* magazine. He predicted that the number of transistors manufacturers would be able to put on a chip would double every year. At the time, a state-of-the-art chip had about 50 transistors. In 1975, Moore revised the doubling period to two years, thinking that the pattern would last at most a decade longer. To his surprise, it still holds true today, as a new Intel chip, code-named Tukwila, hits the market with 2 billion transistors.

He's not entirely averse to the renown the brash prediction has conferred, mind you. "I have to admit," he says with a sheepish grin, "a while back I Googled Murphy's Law and Moore's Law, and Moore's has twice as many references as Murphy's."

Nevertheless, he'd prefer to be remembered as one of the people who started the semiconductor industry, a niche business when he got involved, now generating some US $300 billion in annual sales worldwide. There's no disputing his important roles. He helped develop early silicon transistors at Shockley Semiconductor Laboratory, cofounded Fairchild Semiconductor in 1957, leading the team that produced the first high-frequency silicon transistor, supervised the development of the metal-oxide semiconductor (MOS) process, and created Intel in 1968 with Robert Noyce, building it into an empire with profits of $7 billion a year by the time he retired.

He also helped train an entire cadre of people now running vast parts of the industry. "Gordon was the only boss I ever had," says Andy Grove, to whom Moore turned over Intel's chairmanship in 1997. "He's one of the very few people who shaped my knowledge and understanding and approach as a scientist and a manager. Without Gordon, I would not be me."

It's for all those accomplishments, and more, that he's receiving this year's IEEE Medal of Honor.

But since his retirement from a day-to-day role at Intel, he has been spending his billions in a carefully crafted program of technology- and science-oriented philanthropy that is creating a legacy of its own. As he did half a century ago in electronics, Moore is focusing on big problems. Through the Gordon and Betty Moore Foundation, he and his wife of 57 years are trying to preserve the world's biodiversity, reinvent engineering education, and uncover the secrets of the galaxies.

"When history looks back," says his son Kenneth, "my dad's most important legacy will probably be the foundation. Because while Fairchild and Intel were exceptional companies and important for their time, the foundation may be what really helps the world."

Moore didn't select the foundation's goals haphazardly. He famously calls himself an "accidental entrepreneur," explaining that, had he not been repulsed by William Shockley's abrasive behavior, he would have remained contentedly in the laboratories of Shockley Semiconductor instead of plunging into the stress and risk of managing the start-up Fairchild. Moore's steps into philanthropy, however, have been far more deliberately planned and tie into deep passions.

DURING THE DOT-COM BUBBLE, Intel's valuation soared to half a trillion dollars, pushing Moore's personal wealth to $24 billion. "I had sold essentially none of my Intel stock from the beginning," he says. And yet he never cosseted himself. To this day he takes his own clothes to the dry cleaners, and until recently he flew coach class.

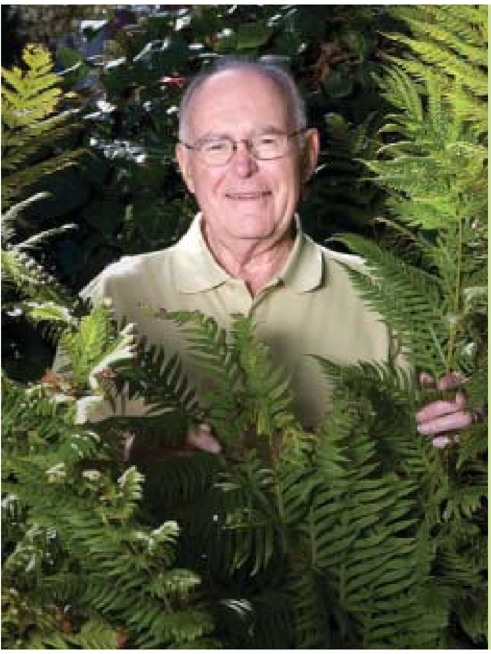
Moore remained involved with Intel until last year while shifting steadily toward his philanthropic activities. He already had a family foundation, started with an endowment of about $20 million in 1986. That foundation now supports causes related to ocean conservation and research, including an ocean research station in French Polynesia and work at the Scripps Research Institute and at the Ocean Conservancy.

In the late 1990s he decided to plow half of the value of his Intel stock into a new charitable foundation. But he didn't want to simply pick someone with philanthropic experience and turn over the money; he wanted this to be a business, run by a businessman.

Finding the right person to lead the nonprofit, even one so well funded, wasn't easy. Then Bank of America Corp. considered but opted not to hire Lewis Coleman for the bank's CEO slot. Coleman, who was then chairman of Montgomery Securities, decided he wanted to change direction in his career, and before long, he found himself talking to Moore. Moore hired Coleman, and the Moore Foundation incorporated in September of 2000.

By then the tech bubble had started to burst. Recalls Kenneth, a former semiconductor industry executive who is now director of evaluation and information technology for the foundation, "The day Dad and Lew signed the papers on an airplane, the endowment was worth $11 billion. The day the foundation actually started it was worth $5.8 billion. The next day it was down to $5 billion." Today it's stable at about $6 billion.

The Moore Foundation has 80 or so employees, and it gives away $300 million annually. Like an entrepreneurial business, the organization creates its projects, writes business plans, and then



GORDON E. MOORE

Current titles: Chairman emeritus, Intel Corp.; cofounder, Gordon and Betty Moore Foundation; chairman, Moore Family Foundation

Date of birth: 3 January 1929

Birthplace: San Francisco

Current residences: Mauna Lani, Hawaii; Woodside, Calif.

Family: Wife Betty; children Kenneth and Steven

Education: B.Sc. from University of California, Berkeley, 1950; Ph.D. in chemistry and physics from California Institute of Technology, Pasadena, 1954

Most recent book read: *Boom! Voices of the Sixties* (2007) by Tom Brokaw

Favorite restaurant: Chef Chu's, Los Altos, Calif.

Car: 1998 Mercedes-Benz 300SD (diesel)

Major awards: IEEE Medal of Honor "for pioneering technical roles in integrated-circuit processing, and leadership in the development of MOS memory, the microprocessor computer, and the semiconductor industry"; Presidential Medal of Freedom (2002); National Medal of Technology (1990)

SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

gives grants to people who will carry out those efforts. It does not consider unsolicited proposals.

THE FOUNDATION made its first grant shortly after incorporating: $261.2 million to Conservation International, in Arlington, Va., a group that buys up open spaces for preservation and monitors biodiversity around the world. It was the largest single donation ever made in the field of conservation.

Moore has long had a fondness for the far-flung corners of the world. He and his wife have spent most of their vacations in some of the world's most remote places, as far from technology and civilization as possible. More often than not during these trips, Moore indulges another passion: fishing. He's fished on the islands of Bikini, Midway, and Vanuatu, on the lonely northwestern coast of Costa Rica, and on Australia's Great Barrier Reef. He's toured virgin wetlands, forests, and grasslands in Brazil's Pantanal region, the Amazon rain forest, and the island of New Guinea. But he says, for the most part, whenever he's gone back to one of these favorite spots 10 or so years later, the magic is gone: forests have been clear cut, fish wiped out, grasslands paved over. Sometimes he finds hotels and golf courses where previously there were spectacular ecosystems and untouched natural beauty. "It's getting harder and harder to find a really remote place," he says wistfully.

IN THE VALLEY, HE'S A LOCAL CELEBRITY, RECOGNIZABLE ENOUGH TO GENERATE A BUZZ WHEN HE WALKS DOWN THE STREET OR INTO A RESTAURANT

Through Conservation International, Moore Foundation funds are supporting an effort to inventory all nonmicrobial life on the French Polynesian island of Moorea, create genetic markers for each species, and make that information available publicly in a database. The group is also expanding the size of the protected area in the Amazon Basin and adjacent forests.

The foundation is funding other organizations that are working to protect marine ecosystems in the Atlantic and Pacific oceans. Those projects include helping improve fisheries management in British Columbia, New England, and the California Current, which runs from western Canada to Baja California. Other efforts aim to protect dwindling wild salmon habitats in Russia's Kamchatka Peninsula, where Moore once fished among the bears, as well as in Alaska and northern British Columbia.

THE CALIFORNIA Institute of Technology, Moore's alma mater, has also benefited handsomely. Early on, the Moore Foundation committed $300 million to Caltech; Moore chipped in another $300 million out of his personal holdings. It's a lot of money for a school with approximately 2100 students.

"Well," Moore says, "it'll take a lot for them to continue to have the influence they've had in the past." The small class size means a small alumni body, he reasons, and therefore fewer resources to tap when it needs to upgrade its facilities or hire a superstar researcher.

Caltech, Moore says, has a unique role in educating engineers and scientists. It's a place where theoretical physicists sit down with electrical engineers at lunch. The $600 million has bought, among other things, a bank of state-of-the-art MRI machines for brain-function analysis as well as lasers and other optics for a new center for ultrafast science. Tens of millions of dollars are going toward creating an international tectonic observatory.

Moore's other great passion, after fishing and wildlife conservation, is astronomy. New discoveries in science are more likely to come from observations of the universe than from doing experiments on Earth, he says. "They'll enable us to understand where we came from and how truly insignificant we are," he adds.

So he's helping fund the world's first optical telescope with a 30-meter-diameter mirror. Moore's foundation has committed $200 million to the project, which is a joint venture of Caltech and the University of California. It will be the largest optical-infrared telescope in the world, with nine times the light-gathering power of the 10-meter Keck telescopes in Hawaii and the Gran Telescopio Canarias in Spain, which are now the world's biggest. It will also have an advanced adaptive optics system. Six laser beams will create luminous spots high in the upper atmosphere; these will serve as reference points, allowing the system to compensate for the atmospheric blurring of starlight. Moore expects to be closely involved in the project because the telescope is probably going to be built on Mauna Kea in Hawaii, near where Moore now lives part-time and where he and his wife are building a Japanese-style home. In the meantime, he makes do with a Meade 8-inch (20-centimeter) Schmidt-Cassegrain telescope with a Go-To electronic pointing system, which his family gave him for a recent birthday.

Moore says his foundation, despite its large size, isn't likely to rush into new fields. Lately, however, it has begun to take on the problems of nursing care. The move was prompted by a couple of very bad hospital experiences that Moore and his wife had. The scariest occurred several years ago, when Betty Moore was in a hospital overnight and a nurse woke her up to give her a shot. Betty insisted that she wasn't due for a shot, but the nurse still injected her with the insulin intended for the woman in the next bed, an error that put two lives at risk. (Yes, even billionaires sometimes get poor care.)

So the foundation has granted about $150 million to a program to assess and improve nursing quality in 39 Bay Area hospitals; it has also granted the University of California, Davis, $100 million to build a new nursing school and will likely take on more nursing-related projects, Moore says.

THESE DAYS, MOORE logs a lot of hours in the air between Hawaii and Silicon Valley. In the past few years, giving in to pressure from friends, he's started flying first class, one of his few extravagances. In the Valley, he attends board meetings, gets his mail, pays bills, and meets with foundation grantees and potential grantees. He's a local celebrity, recognizable enough to generate a buzz when he walks down the street or into a restaurant. In Hawaii, he catches up on his reading and is learning, at age 79, to play golf.

Except, that is, when remote areas of the world beckon, and the fish are biting.

"Venezuela," Gordon Moore says with a sparkle in his eye. "That's next. I'm going to try for bonefish." ❑

TO PROBE FURTHER More information on Gordon E. Moore is available at http://www.spectrum.ieee.org/may08/gemoore.

Plugging Away in a Prius

Continued from page 31

date only to late 2006, so their life expectancy in the field remains unproven.

Although complicated in its own right, the battery swap is not the trickiest part of the conversion. The tougher challenge is figuring out what data to transmit to the Prius's vehicle- and engine-management controllers so that they never "realize" they are working with a battery pack with triple or sextuple the energy capacity of the original.

"We don't modify anything of the original vehicle's controllers," says Lawrence of Hybrids Plus. What the new battery-management system does do is send altered data to those systems—the most important of which is data on the battery's state of charge. With the converted car running in electric-only mode, this state will vary from 90 percent of capacity to less than 40 percent. But a stock Prius is programmed to charge the battery if the state of charge falls below 50 percent and to shed energy by helping to spin the driveshaft when the state rises above 80 percent. So to keep the car running in electric-only mode, a microprocessor in a new "pack controller" that monitors and controls the replacement battery pack keeps sending data within those limits. This allows the vehicle to keep going in pure-electric mode for many miles, telling the controller the state of charge is above 50 percent even as it drops significantly below that.

The added pack controller runs software that's custom written by Hybrids Plus. Besides the software, which lies to the Prius's existing control systems, Hybrids Plus makes hardware modifications. For instance, the lithium-ion packs generate less heat than the stock NiMH pack, Lawrence claims, so they don't require the forced-air cooling provided by an electric fan mounted above the right wheel. The company leaves the fan in place but disconnects it from the vehicle controller.

A standard Prius has many other operating parameters and system checks to ensure the health and longevity of its battery pack, all of which had to be reverse engineered to accommodate the much larger, lithium-ion pack and its peculiar characteristics and also to let the car operate for a few dozen kilometers as a pure EV. Hybrids Plus declined to give specifics on any other software modifications, which it considers its core intellectual property.

CAVEATS ABOUND. A July 2007 Toyota memo expressed concerns about increased hydrocarbon emissions after conversion and cited increased potential for injury after an accident and other risks, such as fire. It also notes that the car's rear-crash safety may be affected by the larger, somewhat heavier battery pack. So far, Hybrids Plus has not performed crash tests on a converted car. The Toyota memo also notes that conversion "voids the express warranty provided by Toyota at the point of sale."

The tailpipe emissions of the converted car may, paradoxically, exceed those of the standard car, perhaps even the maximum limits on the U.S. Environmental Protection Agency's test cycles (the converted car is still "street legal" because those limits apply only to the sale of new cars).

IEEE Candidates in 2008 Election

THE IEEE BOARD OF DIRECTORS has received the names of the following candidates to be placed on this year's ballot. The candidates have been drawn from recommendations made by regional and divisional nominating committees. In addition, the names include candidates for positions in the IEEE Standards Association, IEEE Technical Activities, and IEEE-USA.

Individuals petitioning to be placed on the ballot may do so. Please refer to IEEE Policy 13.7.3. at http://www.ieee.org/web/aboutus/whatis/policies/p13-7.html for specific requirements.

To ensure ballot packages are delivered to the proper mailing address, please visit http://www.ieee.org/coa and update your member profile if necessary.

For more information on IEEE elections and candidates, please visit http://www.ieee.org/elections or contact Carrie Loh, IEEE Corporate Activities, 445 Hoes Lane, Piscataway, NJ 08854, U.S.A.; telephone +1 732 562 3934; fax +1 732 981 1621; e-mail c.loh@ieee.org.

Ballot packages will be mailed to all IEEE members eligible to vote on or before 1 August.

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Researchers from Argonne National Laboratory, in Illinois, tested two Prius plug-in conversions and presented their data at various conferences last year. Neither of those conversions was done by Hybrids Plus—one was by Hymotion Canada, of Concord, Ont., the other by EnergyCS, of Monrovia, Calif. Researchers found that the cars' emissions of hydrocarbons and nitrous oxides equaled or exceeded those of the standard Prius.

The bulk of the emissions occur mainly in the 20 to 40 seconds after ignition, before a car's catalytic converter heats up to the temperatures at which it removes pollutants most effectively. A standard Prius keeps its catalyst at full operating temperature, which makes sense because it operates in pure electric mode for only a fraction of any trip. A PHEV, on the other hand, uses the engine so infrequently that the converter cools down, meaning an emissions spike occurs if the engine has to be switched on suddenly, as when going up a long, steep hill.

> IN THE CAR'S FIRST TWO MONTHS, IT RAN MORE THAN 1000 MILES AND STILL HAD GAS SLOSHING IN THE 45-LITER TANK

But enough nits. Is the car a winner? After driving it for nine weeks, Sawyer says he is delighted. His only complaint is the relatively low speed at which the car automatically switches on its gas engine. He'd like to be able to cruise at 65 or 70 km/h without the engine kicking on. That said, he proudly pointed out that in the car's first two months of operation, it ran more than 1000 miles, and he still had some gas sloshing around in the 45-liter (11.9-gallon) tank from his first and only fill-up. That works out to roughly the magical 100-mpg figure (2.35 L/100 km), obtained by religiously plugging in the car every night and driving it mostly in urban areas and on short trips.

That regimen does take a toll on the Sawyer family's household electricity use, which dad and younger daughter Melanie measured as part of a science project. Recharging the Prius, as expected, was the single largest draw, using an average of 3 to 4 kWh per day. That much energy cost less than $0.50 at Colorado's average rate of $0.093 per kWh in November 2007, when the Sawyers made their calculations. Still, compared with what the gasoline would cost—at the time, about $3.00 a gallon—that's a savings of a few dollars every day when the car is used up to its 48-km range.

The savings are actually higher for Sawyer because much of his electricity comes from his home's photovoltaics and its wind turbine. Even so, getting a full payback on the conversion would require Sawyer to drive half a million kilometers, or 12 times around the equator, just on electricity. (Good luck finding a plug.)

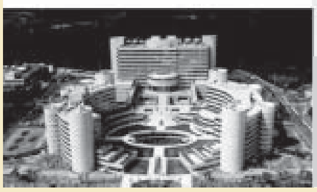
So what's the family's verdict on their plug-in Prius?

"My daughters love the silence and smoothness of plug-ins and electric vehicles," says Sawyer with a grin. "I hope each of them will be able to take her driving test in one."

With six years until the youngest daughter takes the test, that's not out of the realm of possibility. It all depends on how long those lithium-ion batteries last. ❑

Industrial Technology Research Institute

Innovative Technologies for a Better Future



The Industrial Technology Research Institute (ITRI) is a not-for-profit R&D organization, engaging in applied research and industrial services. Founded in 1973, ITRI played a vital role in Taiwan's economic success and is leading industrial research to transform Taiwan manufactured based economy to service & knowledge based economy.

Medical Electronics & Device Technology Center (MED) is one of the research centers within ITRI and contenting medical device research, characterized by Diverse technical resource in electronics, optics, micromachining and chemicals; Market-driven application; R&D engineering and material expertise; Active involvement in business development. Positions for MED are open on:

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Technical Managers and Project Leaders
Ph.D. with working experiences in one of following fields: Medical electronics, Tele-healthcare & medical informatics, Orthopedics / spine fixation devices.

Please email resume to

Mr. Ming-Feng Hsu E-mail: hsumf@ itri.org.tw **http://www.itri.org.tw**

KIT Karlsruhe Institute of Technology

KIT – The cooperation of Forschungszentrum Karlsruhe GmbH and Universität Karlsruhe (TH)

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Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Forschungszentrum Karlsruhe is one of the largest research institutions in Germany and member of the Helmholtz Association of National Research Centres. Presently, Forschungszentrum Karlsruhe (FZK) and Universität Karlsruhe (TH) are merging their activities in the Karlsruhe Institute of Technology, KIT. Within the framework of KIT, applications are requested for the position of

Scientific Director/Head

of the Institute for Data Processing and Electronics of the Forschungszentrum Karlsruhe in association with a professorship (W3) at the Universität Karlsruhe (TH)

The Institute for Data Processing and Electronics (IPE) is active in many research areas of KIT and involved in a number of national and international collaborations. In particular, IPE is specialized in the development of data acquisition systems for applications with high data rates and high time resolution, hardware and software triggers as well as of control systems for large-scale experiments, such as the Pierre Auger Observatory or the experiment KATRIN.

Applicants should have an excellent scientific qualification and international reputation in several of the following areas:

- Real time data processing
- Microprocessor systems and analogue electronics
- Embedded parallel systems
- Software engineering for embedded systems
- Interconnection and packaging technology

Candidates are expected to be highly capable of managing interdisciplinary projects and heading a large institute with many research and service tasks. Experience in the instrumentation of large-scale physics experiments is advantageous. The person to be appointed is expected to represent the above scope of topics also by teaching at one of the faculties of physics, electrical engineering and information technology or information science, depending on his/her qualification. Candidates should have a postdoctoral lecturing qualification or equivalent scientific degree.

Applications of qualified women are strongly encouraged, as we wish to increase the proportion of females at the management level. Handicapped persons with equal qualification will be preferred.

Applications, including a CV, a list of publications, documents about previous research and teaching work as well as offprints of the five most important publications shall, up to **May 13, 2008** be addressed to:

Forschungszentrum Karlsruhe GmbH, Dr. Peter Fritz, Mitglied des Vorstands, P. O. Box 3640, 76021 Karlsruhe, Germany

In addition, we would appreciate the submission of your application documents electronically. **E-mail: peter.fritz@vorstand.fzk.de**

STOKES PROFESSORSHIP

Dublin Institute of Technology

Dublin Institute of Technology was awarded 5 research posts under the Science Foundation Ireland (SFI) Stokes Professorship and Lectureship Programme.
The School of Electrical Engineering Systems, Faculty of Engineering was awarded 2 of these prestigious positions.

The School is a significant player in world renowned interdisciplinary research in electrical engineering. The research encompasses the subdisciplines of digital signal processing applied to audio and speech, power electronics, control theory, health informatics, biomedical engineering and assistive technology (http://eleceng.dit.ie)

The digital audio research group in the School has completed a number of highly successful projects, has published widely and has a licensed patent on novel research in sound source separation. Current projects funded by EU FP6, Enterprise Ireland, HEA Strand 1 & 3 and DIT Abbest, include EASAIER, IMAAS, DiTME and VOCAL.
www.audioresearchgroup.com

The School seeks an internationally recognised candidate for a

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The appointed candidate will receive an attractive salary package together with additional research support from the Institute, underpinning the importance of this position.

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CLOSING DATE
Closing date for receipt of applications is Friday 16th May 2008

For further details and informal discussion contact:
Dr Eugene Coyle, Head of School of Electrical Engineering Systems.
Email: eugene.coyle@dit.ie Tel: 00-353-1-402-4551/4650

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D·I·T Dublin Institute of Technology Institiúid Teicneolaíochta Átha Cliath

KAIST INSTITUTE

FACULTY POSITIONS

at KAIST Institute for Entertainment Engineering

KAIST has established a major research institute for interdisciplinary research in the field of entertainment engineering. The newly established institute aspires to positions of international leadership at the intersection of Computer Science, Electrical Engineering, Mechanical Engineering, and Culture Technology. Successful candidates should have experience in some of the following topics: moving imagery technology (movie, animation, and broadcasting), interactive technology (computer games and ubiquitous life), and experiential technology (entertainment robots, exhibition, digital performance, media arts, digital sound and music). The successful candidates will be appointed as a faculty member at one of the departments at KAIST (primary), and at the same time at KAIST Institute for Entertainment Engineering (secondary).

BENEFITS
- Off-campus university housing
- Seed money (up to US$300,000)
- Immediate access to the graduate students (Both Masters and Ph.D. levels)
- Teaching load is limited to one course per semester

Professor Kwangyun Wohn,
Director, KAIST Institute for Entertainment Engineering
Korea Advanced Institute of Science and Technology (KAIST)
TELEPHONE +82-42-869-2901
E-MAIL wohn@kaist.ac.kr
WEBSITE http://kis.kaist.ac.kr/en/

Position Open

Toyota Technological Institute

has an opening for a faculty position for either a tenured professor or a tenure-track professor in the Department of Advanced Science and Technology.

Research field: Photonics materials and their device-applications.

Qualifications: The successful candidate should have a record of outstanding research achievements and the potential to develop research programs in the above research field. Also, one should be able to supervise doctoral students, and to teach advanced and basic courses on advanced science and technology for graduate and undergraduate students.

Starting date: An earliest convenient time.

Documents: (1) A complete curriculum vitae
(2) A list of publications
(3) Copies of 5 major papers
(4) Brief description of research activities and future plan for research and education (3 pages)
(5) Names of two references with phone/facsimile numbers and E-mail address.

Deadline: August 29 (Friday), 2008

Inquiry: The Chair of Selection Committee
Professor Takao Suzukim (Phone) +81-52-809-1870,
(E-mail) **takaosuzuki2@toyota-ti.ac.jp**

The above should be sent to Mr. Takashi Hirato
Manager, Administration Division
Toyota Technological Institute
2-12-1, Hisakata, Tempaku-ku
Nagoya, 468-8511 Japan

(Please be advised to write "Application for Photonics " in red on an envelope.) Toyota Technological Institute is an equal opportunity educational institute and equal opportunity employer.

NANYANG TECHNOLOGICAL UNIVERSITY

Join the **School of Electrical & Electronic Engineering of the College of Engineering, Nanyang Technological University (www.ntu.edu.sg/eee)**, as a faculty member and embark on a challenging and exciting career in undergraduate/postgraduate teaching, initiating and participating in externally-funded research and academic/professional activities that will enhance the reputation of the School and University as one of the top Technological Universities in the world.

Faculty Appointment

in the area of Human Language Technology

Applications are invited for a tenure-track faculty appointment as Associate/Full Professor in the area of Human Language Technology. Applicants should possess the following:

- A PhD degree and excellent research track record in the area of automatic speech recognition/natural language processing as demonstrated through publications in top-ranked journals, grants awarded, etc;
- Strong academic and research leadership with experience in leading a research group in automatic speech recognition/natural language processing;
- Ability to source for external research funding to contribute to the building of a research centre in human language technology; and
- Good communication skills, as well as willingness and ability to teach at the undergraduate and graduate levels in the general area of human language technology.

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in the areas of VLSI Design & Analog / Mixed-Signal IC Design

Applications are invited for tenure-track faculty appointments as Assistant/Associate Professor in the fields of VLSI Design and Analog/Mixed-Signal IC Design. Applicants should possess the following:

- A PhD degree in EE or in relevant discipline, with an outstanding scholarship record, and a strong commitment to excellence in research and teaching;
- Applicants in the area of VLSI Design: strong background in ASIC design with expertise in VLSI circuits and systems, digital system architecture, system-to-device interaction in digital design, technology scaling, and system-on-chip designs;
- Applicants in the area of Analog/Mixed-Signal IC Design: strong background in analog and mixed-signal IC design;
- Established international standing in at least some of the above areas;
- Ability to contribute towards strategic research focus in low-power system-on-chip design;
- Post-doctoral experience or 2-3 years' working experience in top research institute(s); and
- Experience and exposure to semiconductor ASIC, extraction and verification, system architecture and testing.

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- Interactive & Digital Media
- Real-Time & Embedded Systems
- Information Security
- Biomedical Engineering
- Computer Communication & Networking
- Plasmonics
- Nanophotonics & Nanoelectronics
- Computational Nanoelectronics
- THZ Materials and Devices
- Software Engineering
- Telecommunication Networks & Security

Application Procedure

Suitably qualified candidates are invited to refer to the Guidelines for Submitting an Application for Faculty Appointment (www.ntu.edu.sg/hr/faculty_guidelines.htm) and submit completed applications. **The post applied for should be clearly indicated.**

Electronic submission of application is encouraged and can be forwarded to:

Chair, School of Electrical & Electronic Engineering
NANYANG TECHNOLOGICAL UNIVERSITY
Block S2.1, 50 Nanyang Avenue, Singapore 639798
Fax: (65) 6791-2687
Email: eeehr@ntu.edu.sg

Application closes when the positions are filled.
Only shortlisted candidates will be notified.

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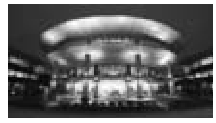

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QUALIFICATIONS PhD in engineering discipline (Electrical, Mechanical, Chemical or Aerospace Engineering) with a specialization in control or electronics systems ● Desirable 8+ years industrial R&D experience and 5+ years technical leadership for project initiative and execution ● Knowledge of electronic data collection, real time distributed architectures, instrumentation, signal processing, control systems, estimation theory or optimization are highly desirable.

RESPONSIBILITIES Provide technical leadership in the research and development of new control and real-time system technology ● Working closely with a global multidisciplinary team executing a vision that impacts the future of GE business as energy, avionics and healthcare; understand market place and industrial trends relate to sensor, controls, real-time computing platform, and communication technology.

Senior/Principal Engineer

Power Electronics Systems — Job code **807891**

QUALIFICATIONS PhD in power electronics or power systems. ● Industrial R&D experience in relevant areas. ● Proven record of technical accomplishments in the related field.

RESPONSIBILITIES Initiate new strategic directions and develop growth strategies in power electronics systems and applications technologies. ● Initiate technical proposals and organize projects in power electronics systems with long-term impacts on GE businesses. ● Mentor and coach junior engineers in technical depth, project execution and career growth in GE.

Senior/Principal Engineer or Scientist

X-ray System and Applications — Job code **805428**

QUALIFICATIONS Ph.D. in Medical Physics, Computer Science, Bio-Medical Engineering, or related field. ● Demonstrated expertise in at least one area relates to X-ray imaging system: Transportation and detection physics, image processing or clinical applications ● Broad x-ray system knowledge from image physics to image processing and link with applications

RESPONSIBILITIES Establish, grow and lead cutting-edge research programs in medical X-ray system and application through close interactions with customers and GE healthcare business unit ● Provide visibility to GE global research and development activities ● Present research at conferences, publish in leading journals, develop patent disclosures ● Identify internal/external collaborations, funding opportunities and develop proposals

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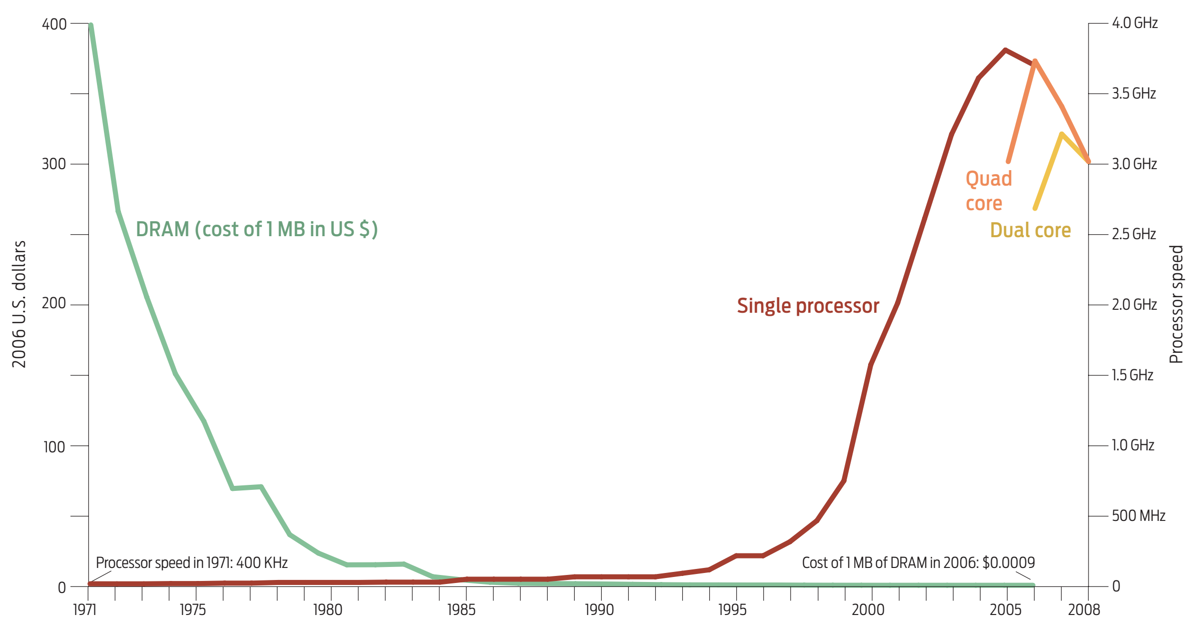
the data BY SALLY ADEE

37 Years of Moore's Law

From 2300 transistors on an Intel 4004 chip to the forest of 2 billion transistors residing on the latest generation of Intel microprocessors, Gordon E. Moore's famous law has guided the steady shrinking of transistors and their consequent density on microchips. That doubling about every two years is how we went from *Pong* in 1972 to the astonishing real-time rendering of hair that moves according to the laws of real-world physics in the video game *Heavenly Sword* in 2007.

Enabling such technological marvels has been the sharp growth of available processing power and the commensurate decline of the cost of DRAM over the past 37 years. Though Moore made his prediction in 1965—which was 45 years ago—it was the concurrent invention of the microprocessor and DRAM in 1971 that sparked the complementary arcs shown below. Because the semiconductor industry advances in lockstep, this curve, though based on Intel chips, is likely representative of the general trend.

Technological advances like personal computers, the Internet, and video games drove these complementary slopes of cost decline and processing-power growth. But just as in the chicken-and-the-egg scenario, those slopes were also the driving force behind the consequent technological advances. Some might balk at the US $399 price tag of an iPhone, but in 1971, its then strictly hypothetical 128 MB of DRAM would have set the consumer back about $50 688 in 2008 dollars. In recent years, processing power has hit a plateau: to continue ramping up performance according to the expectations set by Moore's Law, companies like Intel and AMD have turned to multicore processing. The future path of this graph, therefore, is not necessarily predictable. ❑



CONSUMER

1972: *Odyssey* [above], the first home video game, and *Pong*, the first commercial video game, are released.

1979: Sony debuts the Walkman.

1981: IBM introduces its first personal computer—the IBM PC.

1982: The Commodore 64, the best-selling single personal computer model of all time, debuts, featuring 64-bit graphics.

1997: The BlackBerry device is released by Research in Motion.

1999: Napster brings peer-to-peer file sharing to the masses.

2001: Apple introduces the iPod.

2005: YouTube is launched.

2007: Apple releases the iPhone.

SCIENCE & TECHNOLOGY

1971: Intel invents the first microprocessor.

1973: Xerox introduces the Alto—the first computer with a graphical user interface.

1978: Philips announces the first CD.

1982: Silicon Graphics Inc. (SGI) is launched, sparking an era of high-end 3-D graphics workstations.

1988: Deep Thought becomes the first computer to beat a human chess master. It is later defeated by Garry Kasparov.

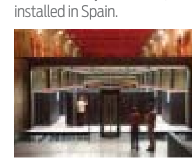
1990: Tim Berners-Lee introduces the World Wide Web to the public on 25 December.

1997: IEEE releases 802.11 (Wi-Fi) standard.

1998: Google fires up its first server.

2004: On 4 January, the NASA rover *Spirit* lands on Mars; *Opportunity* joins it on 25 January.

2005: MareNostrum, a supercomputer with 20 terabytes of RAM, is installed in Spain.



SOURCES: INTEL CORP., VLSI RESEARCH; PHOTOS: TOP, FROM LEFT: MARTIN GOLDBERG/ELECTRONIC ENTERTAINMENT MUSEUM; SONY CORP.; BILL BERTRAM; RIM; APPLE; YOUTUBE; BOTTOM, FROM LEFT: LUCA DETOMI; SGI; CHITOSE SUZUKI/AP PHOTO; NASA; MARENOSTRUM