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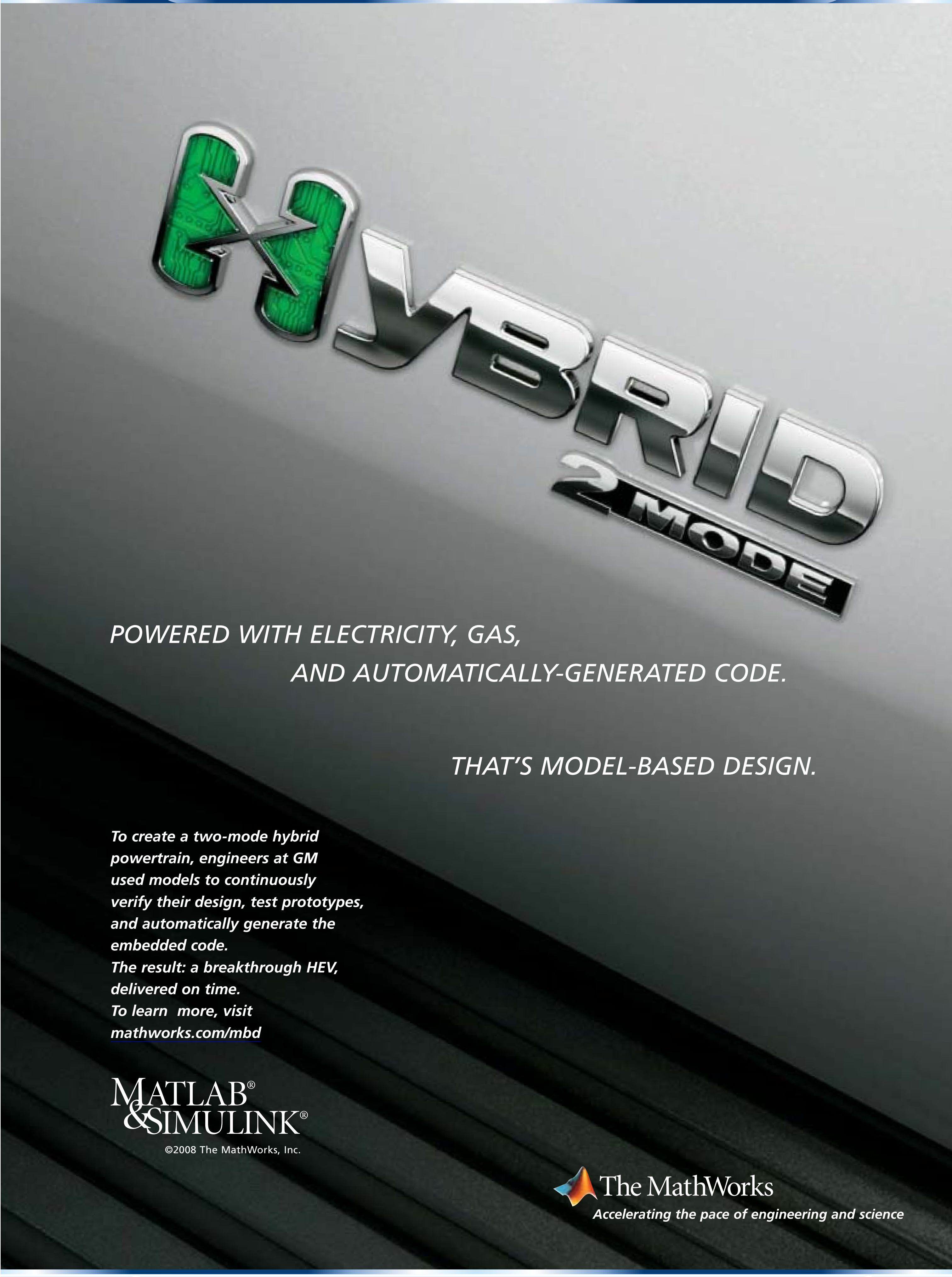
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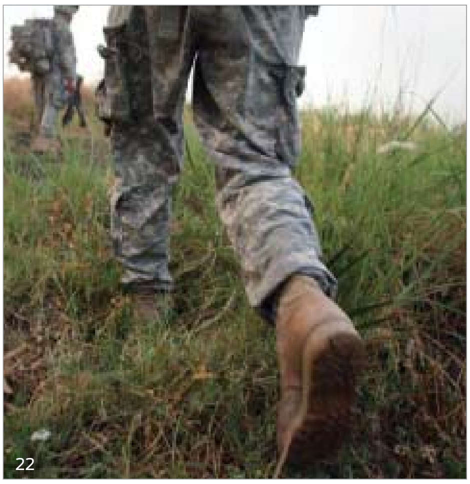

22

32

44

TREAD LIGHTLY
A soldier watches his step in Iraq [top left]; Jon Rubinstein starts a new life, post-iPod, as executive chairman of Palm [right]; and spores evolve into space invaders in the year's hottest computer game [bottom left].

COVER:
PHOTOGRAPHER UNKNOWN. THE SPLIT-SECOND TIMING OF THIS IMAGE OF A HUGE IED BLAST SUGGESTS THAT AN INSURGENT TOOK THE PHOTO. WE ADDED THE SCAN LINES FOR EFFECT.

THIS PAGE, CLOCKWISE FROM TOP LEFT: MICHAEL KAMBER/ THE NEW YORK TIMES/ REDUX; MARK RICHARDS; ELECTRONIC ARTS

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LEFT: EMIRATES; RIGHT: PHOTO-ILLUSTRATION, ANNA DEMIAN; ORIGINAL PHOTO, SIEGFRIED LAYDA/GETTY IMAGES

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For you to re-create at home the same entertainment experience many airlines are starting to offer, your computer, personal electronic devices, cable or satellite system, cellphone, and TiVo would all have to be connected through a touch screen and remote that would be integrated into your fully reclining easy chair. Contributing Editor Robert N. Charette flies the posh skies and talks with in-flight entertainment-system experts about the latest approaches and plans for keeping passengers happy. He also discusses some little-known facts about how these systems are created, as well as how they are used to provide both physiological and psychological comfort to stressed-out jet-setters.

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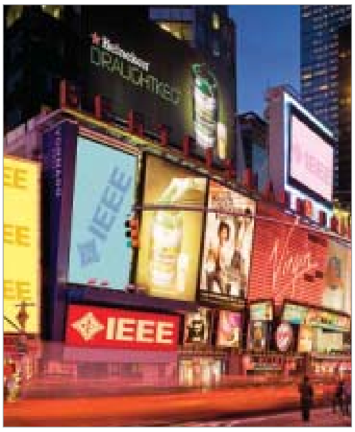
KAM AND RAY HAVE THEIR SAY

Find out what Moshe Kam and Pedro Ray—the candidates for 2009 IEEE President-Elect—have to say about the IEEE issues that matter to members.



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A new IEEE.tv series focuses on the 73-nation Global Earth Observation System of Systems. The three videos give an overview of GEOSS, explore its applications, and feature experts weighing in on the latest Earth-observation technologies.

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

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back story

APRIL JONES

A Computer Game's Intelligent Design

IT WAS one of those 'Oh, wow' moments," says *IEEE Spectrum* Contributing Editor David Kushner [right], recalling his first encounter with the new computer game *Spore*. Due to be released this month and featured in Kushner's article in this issue, *Spore* is the brainchild of legendary game designer Will Wright [left]. Kushner has been a devoted fan of Wright's ever since 1993, when he began playing *SimCity 2000*.

What sets Wright's work apart, Kushner says, is his ability to conjure up those "Oh, wow" moments—lots of them. In *SimCity*, players explore the dynamics of what makes a city thrive, creating uncannily believable and compelling scenarios. "You wouldn't think urban planning and laying down pipe would make for a great computer game," he says. But they did. The game even became part of Kushner's courtship of his wife, Sue: "We spent months having fun building this city together as we were building our relationship." They battled bad plumbing and broken roads, which served as good practice for life in Brooklyn, N.Y. Eventually, their virtual city's inhabitants got to live in a big space tower, so the two won't complain if life continues to mimic art.

When Kushner visited Wright's studio earlier this year, he got a sneak peek at *Spore*'s Creature Creator, the game's built-in editing tool, which lets you sculpt a fanciful new life-form out of a featureless, bean-shaped blob. Kushner was instantly hooked. "Wright's riffing on some basic themes of play, going back to Silly Putty and Play-Doh and Mr. Potato Head," he says. "It's at once new and yet really familiar, with that whimsical quality he's known for."

In the coming months Kushner fully expects to spend many happy hours creating creatures and playing *Spore*. And that's okay, because as a veteran computer-game writer, he actually gets paid to play. ❑

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. 9 (INT), September 2008, p. 7, or in *IEEE Spectrum*, Vol. 45, no. 9 (NA), September 2008, p. 11.

contributors

ROBERT W. LUCKY wonders why engineers are so bad at predicting the future, in this month's Reflections column [p. 16]. Lucky, an IEEE Fellow, holds 11 patents and worked for many years at Bell Labs. Before retiring in 2002, he was vice president for applied research at Telcordia Technologies in Piscataway, N.J.

SEAN McCABE did the photo-illustration for the feature on the new video game *Spore* [p. 32]. The game, in which players design their own creatures and environments, is the brainchild of Will Wright, the man behind the *Sims* franchise. McCabe says, "I wanted to create a fun sort of anime alter reality with Wright sitting in it, ultimately as its God."

MARK RICHARDS photographed Jon Rubinstein, who was instrumental in the development of the iPod, for "From Podfather to Palm's Pilot" [p. 44]. By means of a technique called thin depth of field, Rubinstein appears in focus while everyone and everything else is slightly out of focus. "It allows you to see the people but not see the people," Richards says. His work has appeared in *Life*, *Wired*, and *The New York Times Magazine*.

BRUCE SCHNEIER reviewed Clay Shirky's book about the organizational power of the Internet, which makes possible projects like Wikipedia but also helps hate groups communicate [p. 19]. An internationally recognized expert on computer security, Schneier is chief security technical officer of the BT Group's Managed Security Services. His best seller *Applied Cryptography* (1995) is considered the definitive book on the subject.

BRIAN STAUFFER created the incendiary illustration for our Careers story "Extremist Engineers" [p. 18]. His cover for the 13 November 2000 issue of *The Nation* was honored by the American Society of Magazine Editors as one of the top magazine covers of the past 40 years. Stauffer's work has also appeared in *The New York Times*, *Rolling Stone*, and *Time*.

JEONG SUH & AARON WIESINGER, of Bryan Christie Design, teamed up to create the opening illustration for "Beyond Silicon's Elemental Logic" [p. 38]. Suh is a recent graduate of Michigan State University's digital media arts and technology program, and Wiesinger is finishing his master's in the same program.

PEIDE D. YE, author of "Beyond Silicon's Elemental Logic" [p. 38], is an associate professor of electrical engineering at Purdue University, where he's known as Peter. He adopted the nickname at Bell Labs, where he and his many co-workers in semiconductor research were required to wear special blue suits and head coverings in the clean rooms, which made it hard to identify who was who. In this "blue zoo," as they called it, having a name that Westerners could easily recognize proved a definite plus.

CLOCKWISE FROM TOP LEFT: STEPHEN LACKO; BRIAN STAUFFER; PURDUE UNIVERSITY; GEOFFREY STONE; MARK RICHARDS; ANNIE CHIU spectral lines

The Future Of Code, Digital And Genetic

DEBATING THE FUTURE OF SOFTWARE: From left, Thoughtworks founder Neville "Roy" Singham, David Heinemeier Hansson, Charles Simonyi, and Grady Booch take center stage at *Fortune* magazine's Brainstorm Tech. PHOTO: STEVE JURVETSON

THE CROWD at this summer's Brainstorm Tech Conference, organized by *Fortune* magazine, was atwitter with social networking and mobile technologies and the myriad other ways in which we continue to tether ourselves to the Internet and one another. We were, of course, at Half Moon Bay, Calif., near the U.S. epicenter of the metaverse, Silicon Valley.

Two of the meeting's sessions, however, fell beyond the Internet's gravitational pull. Although these topics attracted far less buzz than some of the rest, they could ultimately have more impact on tech industries than all the current Internet crazes combined.

An all-star programming panel—"The Future of Code"—featured David Heinemeier Hansson, creator of Ruby on Rails (RoR), the highly regarded open-source Web-applications development platform; Charles Simonyi, space tourist, renowned Microsoft developer, and now CEO of Intentional Software; and object-oriented programming guru and IBM's chief scientist for software engineering, Grady Booch.

The discussion poked at the elephant in the server room: most software projects fail; most software is more complicated and enigmatic than the problem it's trying to solve; most software is just plain bad. So how can it be done better—a lot better?

Hansson, not surprisingly, championed small-is-better open-source solutions. He pointed out that most problems solved by software today don't require fail-safe killer apps created by Microsoft-size teams; they require robust but properly sized small-team solutions.

But Booch reminded the audience that software development is very difficult and that RoR-type solutions can't be applied to everything, particularly when software is being asked to solve large-scale critical infrastructure "system of systems" problems. That's why, if you get far enough into the little Everything Mac user guide that comes with your new Macintosh computer, you'll find:

> This computer system is not intended for use in the operation of nuclear facilities, aircraft navigation or communications systems, or air traffic control machines, or for any other uses where the failure of your computer system could lead to death, personal injury, or severe environmental damage.

In other words, it's tolerable if the operating system running your Mac or the RoR software running your favorite Web site seizes up or crashes from time to time. It's not okay if the software running JFK International Airport's air-traffic-control system suddenly cuts out. And that was Booch's point. There's software, and then there's *software*.

Simonyi talked about his "intentional software" concept. If the human genome can be encoded in a program that takes up less than 1 gigabyte, he asked, why does Windows require 15 or 16? So, instead of building software according to elaborate blueprints that detail every programming step, Simonyi is following what he called a recipe approach. His team at Intentional Software creates a set of programming tools, writes a very specific description of the problem they are attempting to solve, and then uses the tools to generate a software solution. It sounds like a software version of the directed self-assembly techniques used in chemistry and nanotechnology.

Over on the in vivo side of the house, Harvard's George Church, biotechnologist and founder of the Personal Genome Project; Drew Endy, of Stanford University and a founder of the BioBricks Foundation; and Rodney Brooks, of MIT and iRobot, discussed what's being called synthetic biology or synthetic life research. The goal of this work is to build biological systems from standard interchangeable genetic parts that can then be used to manufacture everything from biofuels to transistor parts, or as Brooks put it, "to assemble the furniture without having to grow the tree first."

Sound far-fetched? Undergraduate students participating in the annual International Genetically Engineered Machines competition have already programmed bacteria to make computational logic devices. In fact, synthetic biology is proceeding so fast that Endy and his colleagues are setting up forums to discuss its regulation by the research community.

So what happens if using synthetic genetic material in manufacturing becomes widespread, or if Simonyi is right and it becomes possible for software programs to assemble themselves? We're guessing that these technology upheavals will make the Twitter/Facebook "revolution" seem oh so yesterday. —SUSAN HASSLER

forum

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MORE NOTES ON THE SINGULARITY

While Robin Hanson raises some thought-provoking points in his article "Economics of the Singularity" [June], there is one argument I strongly disagree with. Hanson assumes that the first intelligent machines will be exact copies of human brains. I think that most researchers in neuroscience or intelligent systems would agree that this will not be the case. We are far from having the technology that could scan and exactly reproduce the functional structure of a system as complex as the brain. But even if we could, a mere static copy of a brain would not display humanlike behavior. For this we also would have to reproduce the self-adaptive qualities of the brain, which continuously modify its structure and, consequently, its input-output behavior. Once we have achieved this—assuming it will ever happen—there will be no economical reason to build exact replicas of human minds. Instead we would build intelligent agents for very specific tasks. These agents would at least be alien to human minds, and there is no reason to believe that their intelligence would not continue to grow.

Philipp Wolfrum
IEEE Student Member
Frankfurt, Germany

I greatly enjoyed reading about the singularity but wonder why its advocates ignore the fundamental difference between computer models and reality. For example, Christof Koch and Giulio Tononi ["Can Machines Be Conscious?" June] correctly observe that consciousness is part of the natural world, but their conclusion that consciousness functions only through mathematics and logic is false. While a computer model may simulate the hydraulic pressure in a heart, this simulated pressure can't pump real blood. In the same way, a computer may simulate certain aspects of consciousness, but this artificial intelligence will never be conscious itself.

The human brain operates on reality, not numbers. Numbers are only attributes of reality, not the whole of it. Indeed, the logician Kurt Gödel proved in 1930 in his famous incompleteness theorem that mathematics is incomplete; often you must go outside of mathematics to arrive at truth. Gödel's theorem is the equivalent of saying there are valid computations that will never be complete. The only possible response of a robot to much of reality is, "It does not compute." To be human means to experience life. While simulating life and its many processes can bring wonderful benefits to mankind, confusing simulations with reality is harmful and absurd.

Zoltan Cendes
IEEE Fellow
Pittsburgh

"The Consciousness Conundrum" [June] was a well-thought-out, well-documented article on the fantasy of the singularity. British neurobiologist Steven Rose, one of the experts cited, asserts that our minds require the medium of "a social, crafty, emotional, sex-obsessed flesh-and-blood primate," which almost says it all. I would add that an essential part of our being is our mortality. It provides a large part of our motivation for many of our most defining achievements, including child rearing, teaching, writing, art, science, and dreams of the singularity. Mortality also clears the Darwinian deck for the next generation to evolve. If the lives of all our ancestors had been twice as long, the sun would have gone into overheat mode long before something like us could evolve and do something about it. So let's not be too quick to frustrate the life-and-death process that has been such an important part of us and our ancestors.

Michael Mallary
IEEE Fellow
Harmony, Pa.

CORRECTION We would like to credit Henry Markram, of the Brain Mind Institute at Ecole Polytechnique Fédérale de Lausanne, as the original source of the images on the Contents page and in "The Consciousness Conundrum" [above] in our June issue. Markram's work on the Blue Brain project was the source of the images.

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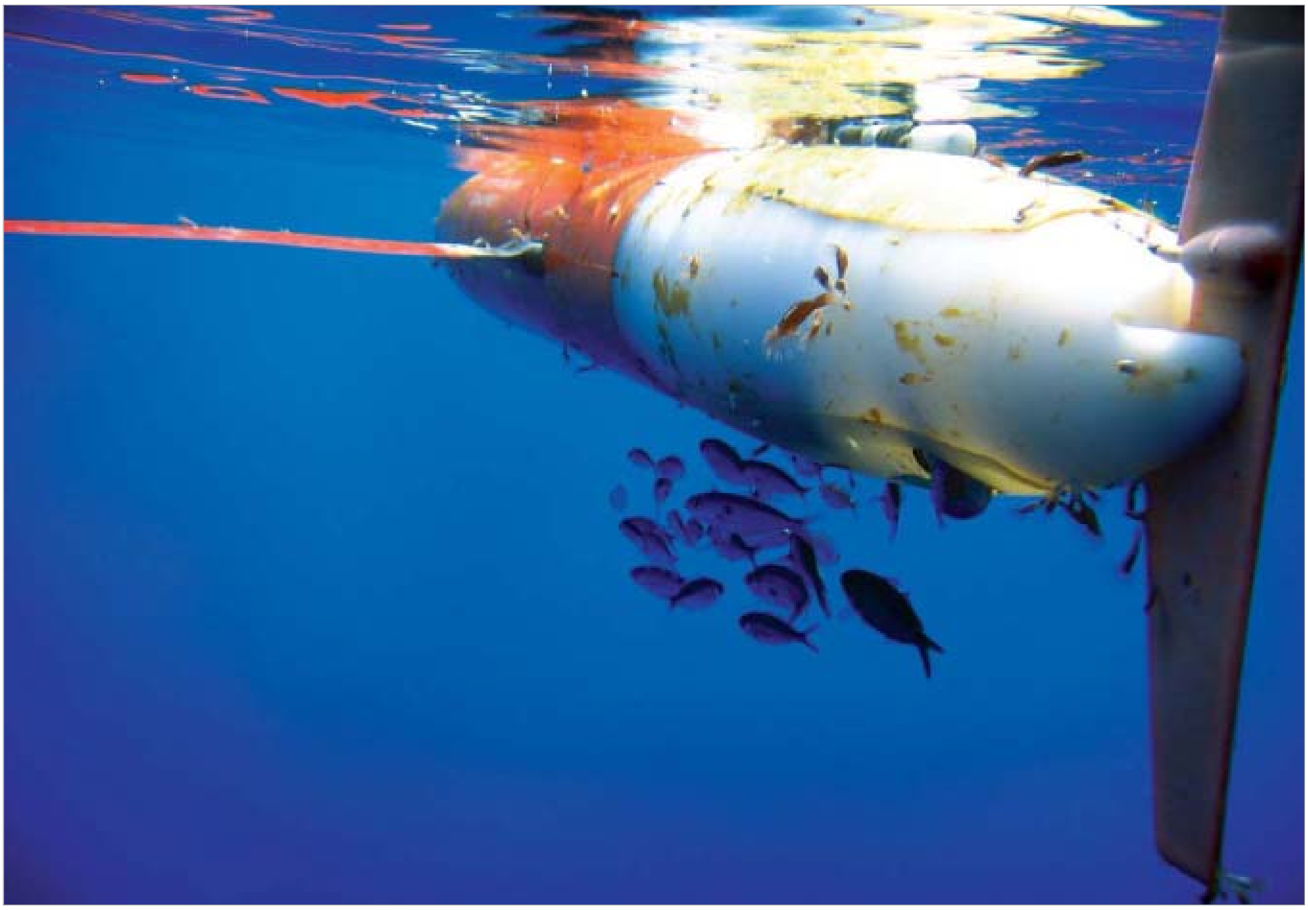


Defense Contractors Snap Up Submersible Robot Gliders

U.S. Navy contract stirs interest in propellerless AUVs

SCHOOLS OF small fish follow them for company or shade, but sharks, less friendly, have on occasion chomped on their elongated bodies. These new arrivals to the underwater world are small submersible robots known as gliders because they thrust themselves through the water not with propellers but by simply changing their buoyancy. Thanks to this neat trick, gliders consume just a trickle of power and can remain at sea for several months at a time, surfacing only to get a GPS fix and beam data to satellites. A mission using a conventional autonomous underwater vehicle (AUV) lasts only hours.

Now it seems gliders have caught the attention of some other big fish. This month, the U.S. Navy plans to announce the winner of a contract for 154 gliders, plus spare parts, launch-and-recovery equipment, and monitoring systems. The order, valued at tens of millions of dollars, sent defense contractors racing to gobble up the leading glider technologies.

In June, iRobot, in Bedford, Mass., best known for its Roomba vacuum cleaner and bomb-disposal PackBot, became the exclusive licensee of Seaglider, developed at the University of Washington, in Seattle. In July, defense industry giant Teledyne Technologies acquired Webb Research, in East Falmouth, Mass., creator of the Slocum glider. General Dynamics had earlier subcontracted Bluefin Robotics, in Cambridge, Mass., a licensee of the Spray, a glider jointly developed

THE LIFE AQUATIC: A Spray robot glider gathered data for three months in the Solomon Sea, east of Papua New Guinea, where a French-U.S. research team is studying how regional currents affect El Niño cycles. The Spray is one of three designs competing for a U.S. Navy contract.
PHOTO: CHRISTOPHE MAES/CENTRE IRD

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

update

by the Scripps Institution of Oceanography and the Woods Hole Oceanographic Institution.

The Navy solicitation, part of a larger program called Littoral Battlespace Sensing, Fusion, and Integration, involves using fleets of gliders to gather data on ocean currents and on acoustic properties that may affect military sonar systems. The Navy deal "got a lot of attention because right now people are buying gliders in ones and twos and threes, so it's a big increment," says Russ Davis, an oceanographer at Scripps, which is part of the University of California, San Diego. Gliders are enticing, he says, because of their relatively low cost: a fully equipped unit sells for about US $100 000 and can go for six months; a data-gathering mission using a ship can cost over $30 000 a day.

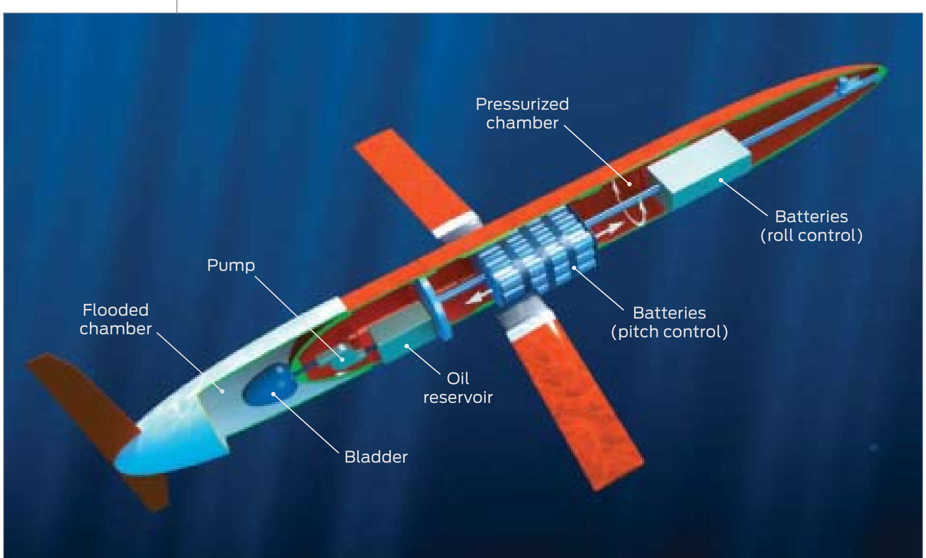
Up to this point, however, AUVs have been a cottage industry. "The challenge now is making the transition from this very hands-on build-and-test kind of manufacturing to commercial production mode," says Tom Curtin, chief knowledge officer at the Association for Unmanned Vehicle Systems International, a trade organization in Arlington, Va.

The Navy contract will pit the three main glider designs against one another. As it happens, they all emerged from the same Office of Naval Research program in the mid-1990s. Similar in design, each is a torpedo-shaped aluminum hull about 1.5 to 2 meters long crammed with sensors, batteries, and electronics. To move, the glider uses a pump to inject or remove oil from a bladder located in a flooded part of the hull. To ascend, a robot expands the bladder, displacing water and increasing its buoyancy; to descend, it empties the bladder out. A pair of fixed wings converts part of the vertical displacement into horizontal motion, causing the glider to travel in a sawtooth trajectory.

To change pitch while climbing or sinking or to turn left or right, the gliders change their center of mass by shifting the position of their battery packs. "There are no external moving parts—no propellers or jets or moving fins—to push this thing through the water," says Tom Frost, iRobot's program manager for the Seaglider. "It's really elegant."

And even though their original designs are alike, their makers boast of unique capabilities. iRobot claims the Seaglider has the longest range and battery lifetime, being the first glider to complete a mission of more than 3750 kilometers and lasting six months. Bluefin, which is also supplying an offshore oil and gas contractor, says the Spray glider can go about 50 percent deeper—1500 meters—than its competitors and has more durable sensors. And Teledyne says the Slocum's rudder gives it better shallow-water maneuverability and that a new system that harvests energy from temperature variations in the water could allow its gliders to stay at sea for years at a time.

For researchers like Scott Glenn, a professor of physical oceanography at Rutgers University, in New Brunswick, N.J., any extension of a glider's time at sea is welcome news. In the past few years, Glenn and others have turned to gliders to study ocean circulation, climate events, and marine life. One of his projects involves tracking the flow of sediments off New Jersey's coast during storms. He and his colleagues can't go out on research boats in those conditions, but with gliders they can be anywhere there's an Internet connection to monitor—or "fly"—the vehicles. "I do a lot of flying from McDonald's or Starbucks," Glenn says. "Anywhere, anytime, you can go to sea." —Erico Guizzo



POWER, SANS PROPELLERS: A glider rises by inflating a bladder with oil and sinks by deflating the bladder. The fixed wings convert vertical motion into horizontal, and the glider displaces its batteries to control roll and pitch. *ILLUSTRATION: JOHN MacNEILL*

update

Virtual-Reality Test Reveals Hidden Concussion Damage

A technology that can tell when athletes are ready to get back in the game

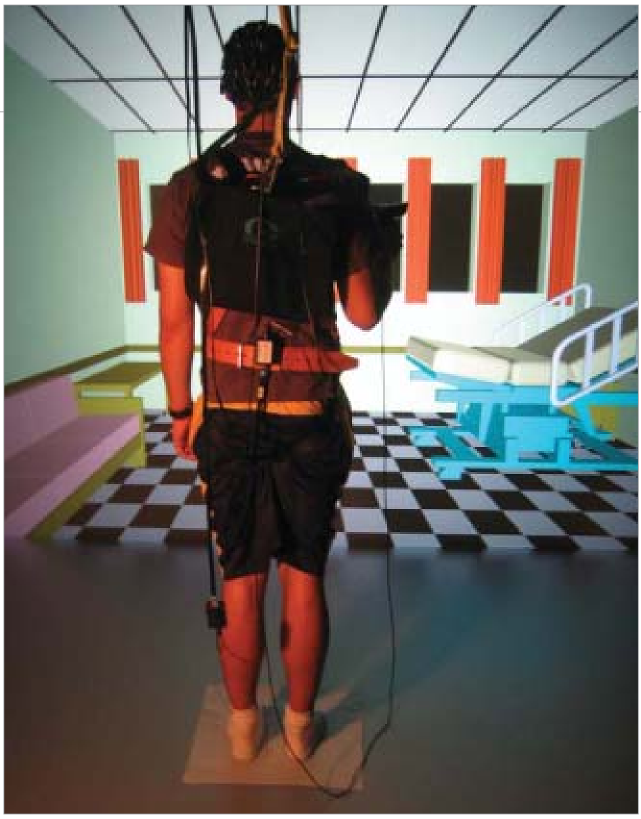
Autumn is upon us, and in the United States, so is football season. The players, who deliver jarring hits to one another that often equal the force of car wrecks, are lionized for the ability to, in the words of an old watch commercial, "take a licking and keep on ticking." But concussions are not uncommon, and new research shows that even when players are symptom-free and have passed a battery of cognitive-function tests, their brains may not have completely recovered and may still be vulnerable to further injury.

An ongoing study at Pennsylvania State University aims to create a reliable electroencephalography system for judging whether an athlete should get back in the game, stay on the sidelines, or call it quits.

In an early round of the study, to be published in *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 61 football, rugby, and soccer players at Penn State (male and female) were examined; 30 of them were chosen because they had suffered concussions 30 days prior to participating in the study but had been cleared for a full return to their sports. Each subject was connected to an electroencephalograph via 19 electrodes attached to his or her scalp and earlobes and was asked to stand on a platform studded with sensors that recorded shifts in pressure distribution at the bottom of the feet. The platform was surrounded on three sides by video screens that created a visually immersive environment.

A computer running a proprietary algorithm recorded and synchronized the subjects' physical and neurological responses to virtual-reality graphics. The graphics were designed to give participants the sense that they were involved in some situation that provokes a physical response—say, riding a roller coaster or participating in a snowball fight.

The control group, made up of players who had not suffered concussions, mostly did what was expected when presented with virtual situations that called for complicated, coordinated responses using multiple body parts, and their brain-wave patterns were ordinary. Using the control data, the system became increasingly adept at identifying previously concussed athletes, who exhibited delayed reaction times and abnormal physical reactions like using too little or too much force. Nearly 97 percent of the time, these abnormalities in motor coordination corresponded to detectable differences in the athletes' brain waves compared with baseline readings taken before the start of their competitive seasons.



VIRTUAL EXAMINATION: To assess athletes' injuries, scientists measure motion and brain waves in response to virtual situations.
PHOTO: ELENA SLOBOUNOV

According to research associate Richard L. Tutwiler, the Penn State researchers are refining the technique and gathering a pool of data they think will be large enough to yield a reliable brain assessment tool within two years. "The hope is that we can then make a portable unit that can begin taking readings right after a player gets off the field," he says.

Stefan Duma, director of Virginia Polytechnic University's Center for Injury Biomechanics and the lead researcher on the Head Impact Telemetry program (HIT), applauds the Penn State researchers' efforts. The HIT system, developed by researchers at Simbex, of Lebanon, N.H., and at Virginia Tech and Brown universities, uses helmet-mounted sensors to measure the force of collisions. It then alerts coaches and trainers to those collisions likely to have resulted in concussions, based on data from more than 30 000 impacts. [See "Helmets Sense the Hard Knocks," *IEEE Spectrum*, October 2007.]

Jeffrey Chu, Simbex's director of engineering, says that Penn State's test and HIT would be complementary technologies. "HIT gives sideline staff a powerful tool by putting the focus on players likely to have suffered a brain injury," says Chu. "A device based on EEG or other assessment tools would pick up from there, determining the extent of the damage." —Willie D. Jones

Breaking Quantum Cryptography's 150-Kilometer Limit

Scientists want to put an unbreakable-code generator on the International Space Station

RESEARCHERS IN Europe in the field of quantum cryptography have demonstrated for the first time that it should be possible—with the help of satellites—to communicate across thousands of kilometers using unbreakable codes whose security is guaranteed by the laws of quantum physics. For many business or government uses, the codes must be usable between cities and continents, but quantum cryptography machines today are limited to about 150 kilometers by the length of individual optical fibers and the loss of photons within them.

The team that performed the experiment, made up of researchers from Italy and Austria, did not actually encrypt a message, but they demonstrated a key principle: the detection of single photons sent from a satellite. This month they will present a plan to the European Space Agency to install a quantum cryptography system on the International Space Station (ISS) and use it to perform the first satellite-based quantum communication.

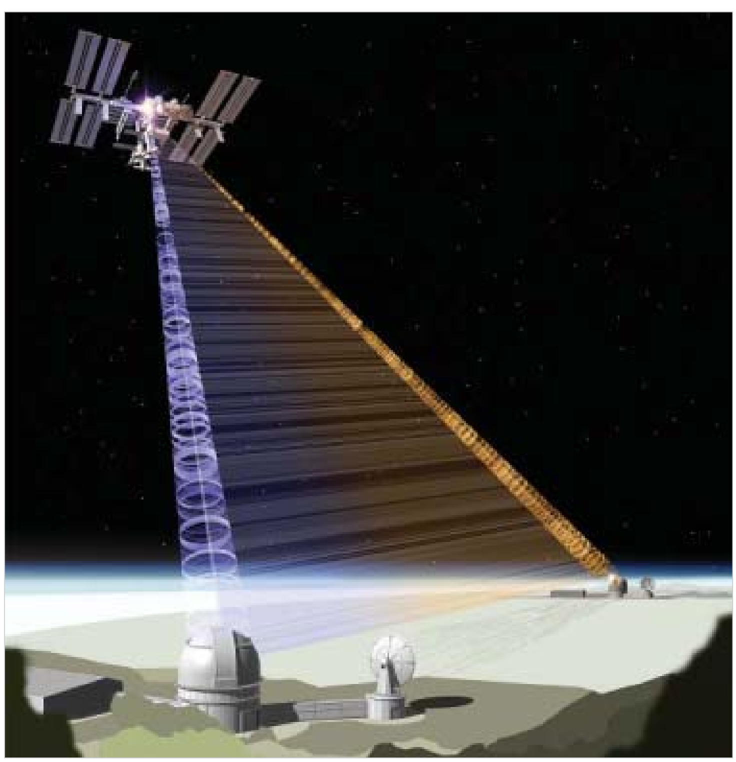
The researchers, led by Paolo Villoresi at the University of Padua, used the Matera Laser Ranging Observatory, in Italy, to bounce weak laser pulses off the Ajisai satellite, a mirrored orbiter 1485 km up. What returned to the observatory were single photons.

Single-photon exchange is important because it provides part of the security of quantum cryptography. In a common scheme, single photons are converted into "entangled pairs"—pairs of photons that are mutually dependent, even when they travel far apart. Quantum theory says that if you measure one of the photons in an entangled pair, the properties of the other are also instantly revealed. For the purposes of quantum cryptography, the pairs are split up and sent to the parties wishing to communicate secretly. Through a series of steps involving polarization filters and other measures, the photons produce the same random series of bits, or quantum key, for each party. In theory, no one can intercept individual photons and steal the key, because any attempt to do so would alter the key in an easily detectable way.

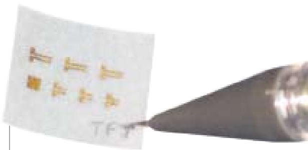
The difficulty lies in preserving the entanglement over long distances. The success of the Ajisai experiment demonstrates that a source of single photons on a satellite can indeed be detected at a ground station many hundreds of kilometers away, against very high background noise.

The success with Ajisai "is an important step, as many of the potential problems, such as timing and tracking, have been proven to be in a manageable regime," says Norbert Lütkenhaus, professor at the Institute for Quantum Computing at the University of Waterloo, in Canada, who was not involved in the research.

For the proposed ISS experiment, the entangled photons would be beamed from orbit to two distant ground stations, allowing them to communicate using the quantum key. —SASWATO R. DAS



SECRETS BY SATELLITE: Scientists propose installing a quantum cryptography system on the International Space Station that would generate an unbreakable code from entangled pairs of photons. ILLUSTRATION: EUROPEAN SPACE AGENCY, GENERAL STUDIES PROGRAMME



PAPER TRANSISTOR

Researchers from Universidade Nova de Lisboa in Portugal say they've made a transistor using paper as both the substrate and the dielectric layer. Elvira Fortunato, lead author of the study in this month's *IEEE Electron Device Letters*, says that oxide semiconductors are compatible with paper because they can be built at room temperature. The paper transistor performed similarly to a transistor on a glass substrate, she says. Fortunato wants to use the transistors for low-cost disposable microelectronics like biosensors and smart packaging.

PHOTO: SONIA PEREIRA & NUNO CORREIA

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

WE'RE LISTENING: Forty-two radio dishes in Hat Creek, Calif., will start listening for signs of extraterrestrials this month.
PHOTO: SETH SHOSTAK

Allen Telescope Array Starts Search for E.T.

Radio telescope array will seek out new life and new civilizations

IT'S SMALLER than originally hoped for, but with 42 radio antennas the Allen Telescope Array, or ATA, is the most advanced structure ever built to look for signs of extraterrestrial intelligence. Following technical delays and cost overruns that left it well short of its planned size, the array is expected to begin its mission full-time this month. It began performing radio astronomy last year but wasn't ready to look for artificial radio signals until now.

"We are doing final calibration, testing, and repairs and expect to begin with the first SETI program by about September 1," Leo Blitz, director of ATA and the Radio Astronomy Laboratory at the University of California, Berkeley, told *IEEE Spectrum*.

Thanks in part to a gift of US $25 million from Microsoft Corp. cofounder Paul Allen, the SETI Institute (for Search for Extraterrestrial Intelligence) will have its own powerful observatory to search the skies, rather than having to comb through data gathered from other telescopes' observations. The ATA, nestled in a remote volcanic valley about 460 kilometers northeast of San Francisco, will be the first privately funded major radio telescope observatory. However, the original array plan called for 350 dishes. "The technical challenges wound up significantly adding to costs and producing delays. Building up to a 350-element array depends on getting enough financing to finish it," says Blitz. "We need another $45 million, so checks are welcome."

The original plan called for the purchase of inexpensive 6-meter radio dishes from a commercial product line, but these picked up too much background interference. So the ATA had to go with a more expensive, custom-built design. In addition, the array requires a pointing and tracking system with much greater accuracy than what commercial systems are capable of. So the designers had to invent a new system from scratch, adding to the delays and costs.

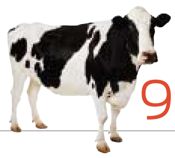
The resolution of a radio telescope is proportional to the size of the dish, but if many smaller, cheaper ones are electronically linked, they will have the same resolution as a single large dish. This works because a system called a correlator tracks the differences between the phases of radio waves as they reach the various dishes. This phase information can then be used to construct the same kind of radio image that a single, larger radio dish would provide. From each of the antennas, a broadband feed collects signals over the range of 0.5 to 11.2 gigahertz. The signal from the sky is then amplified over the entire frequency band, encoded onto a laser, and sent over an optical fiber to the control room, where it is digitized and processed.

"The unique aspect is that ATA will be able to conduct radio astronomy and SETI at the same time," says Blitz. The array's amplification system allows the signals to be split into four independent frequencies, and all four can be analyzed at once—usually two for astronomy and two for SETI.

Seth Shostak, senior astronomer at the SETI Institute, says the first signals they will look for are "in a large area in the general direction of the center of the Milky Way, to see if there are any 'super-transmitters' sending out signals from advanced civilizations." Shostak predicts that with the ATA, the first signals from an advanced civilization could be detected within the next 25 years.

"I think that most astronomers believe that there must be intelligent life somewhere out there," says Arpad Szomoru, head of technical operations and R&D for the Joint Institute for Very Long Baseline Interferometry in Europe, which recently electronically linked radio telescopes around the world [see "Earth-Size Radio Telescope Opens Its Eye," *IEEE Spectrum*, August 2008]. "Whether SETI has a chance of detecting this is unclear, but as technology advances and instrumentation becomes more sensitive, who knows?"

—BARRY E. DIGREGORIO



99 MILLION The metric tonnage of greenhouse gas the United States would *not* emit if it used biogas from livestock manure to generate electricity, according to researchers at the University of Texas at Austin

World's Most Powerful Magnet Under Construction

One hundred tesla without self-destructing

MAGNETIC MOMENT: Engineers are readying a supercooled, record-setting 100-tesla magnet at Los Alamos National Laboratory. The magnet will have to withstand forces equivalent to 200 sticks of dynamite. PHOTO: LEROY N. SANCHEZ/LOS ALAMOS NATIONAL LABORATORY

MULTIPLY THE magnetic field strength of a refrigerator magnet by 2 million and you'll be in the ballpark of the strength of the magnet that researchers at the National High Magnetic Field Laboratory, based near Florida State University in Tallahassee, are trying to create. When completed later this year, the pulsed electromagnet, located at the lab's facility at the Los Alamos National Laboratory, in New Mexico, will reach 100 tesla, the holy grail of magnetic field strength. And in another first, if all goes according to plan it will reach that level—about 67 times as high as a typical MRI—without blowing itself to smithereens.

Why would anyone need a magnet that strong? Greg Boebinger, director of the Magnet Lab, says that this magnetic field strength is the only way to test the properties of newly discovered high-temperature superconductors like iron oxyarsenide, which may improve the performance of MRI machines and high-voltage power lines while lowering their cost. A 100-T magnet would also let you conduct certain zero-gravity experiments without traveling into space and let you develop magnetic propulsion systems that could eventually replace those that burn rocket fuel.

So far, researchers have reached 90 T, proving that the Magnet Lab is on the right track. "We've been running it at the hairy edge," Boebinger says, referring to the tradeoffs he and his colleagues must make to get the most out of the magnet without destroying it in the process. Researchers have been able to generate magnetic fields stronger than 100 T for years but knew that any such experiment was a one-and-done situation, because these magnets would almost instantly be torn apart by their own forces.

Boebinger says the Magnet Lab is close to reaching the material tensile strength needed to repeatedly break the 100-T barrier. That is no small feat, considering that the US $10 million magnet will have to resist enormous Lorentz forces—the electromagnetic push on electrons that attempts to force them in a direction perpendicular to the flow of current. In a magnet that strong, says Boebinger, these forces are "equivalent to the explosive force of 200 sticks of dynamite packed into a volume of space the size of a marble."

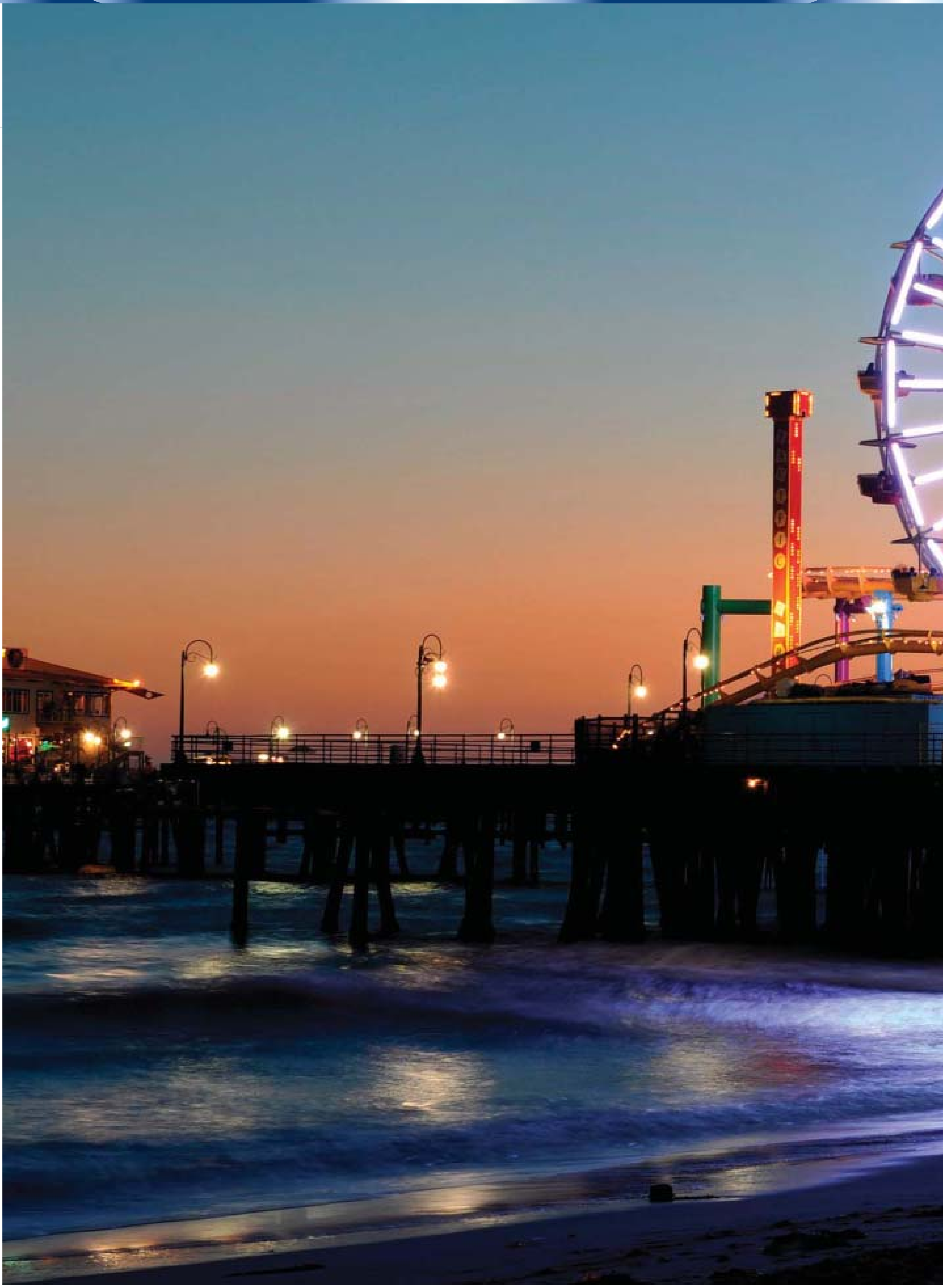
The electromagnet will be made of two pieces—a thick, hollow cylinder, called an outsert, that's 1.5 meters in diameter by 1.5 meters tall, and an insert just big enough to fit inside the outsert's 225-millimeter bore. The outsert will be powered by a 1.4-gigawatt generator and produce fields between 40 T and 44 T, while the insert will draw enough current from a 2-megajoule capacitor bank to generate fields up to 60 T. The outsert is never powered up for more than 2 seconds at a time, during which the insert can deliver multiple 20-millisecond bursts. Enough energy is transferred during those 2 seconds to raise the magnet's temperature from the cryogenic cold of liquid nitrogen to nearly 200 °C. It takes an hour to cool the magnet enough to start another round of pulses. Boebinger says the design and composition will allow researchers to get roughly 10 000 pulses out of the $8 million outsert magnet and about 100 pulses before a $20 000 insert magnet is destroyed.

"Simply put, pulse magnets are applied metal fatigue," says Boebinger. "The trick is to hold off the breakdown of the bonds between the molecules due to mechanical and thermal stresses for as long as you can."

Several ingredients in the secret sauce will let this magnet snap back where others have simply snapped. The magnet is made up of nine nested coils of wire. At the heart of the two innermost coils, where Lorentz forces create pressures 30 times as great as those at the bottom of the ocean, researchers have placed state-of-the-art nanoparticle wire composed of 82 percent copper and threaded through with silver strands no more than a few hundred atoms across. The copper-silver combination is stronger than either metal alone by a factor of 100.

From there, things get a little easier, if only on the wallet. "The further out you go, the lesser the forces are," says Boebinger, "so you can afford to use material that is not as strong and not nearly as expensive." —WILLIE D. JONES

GK AND VIKKI HART/GETTY IMAGES



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

the big picture

ENERGY LOOP
It's after dusk, but this brilliantly illuminated Ferris wheel, perched atop the Santa Monica Pier in California, is being powered by the sun. Well, sort of. During the day, its 650 solar panels generate up to 71 000 kilowatt-hours of energy—enough to spin the 27-meter-high wheel and shunt current to the power grid. After dark, it draws back the power it put in. This past summer, the park replaced an older solar Ferris wheel, which burned 5400 incandescent bulbs, with this US $1.5 million model and its 160 000 LEDs. The new wheel's lights use only one-quarter of the energy consumed by the bulbs. What became of the older model? Sold on eBay for $130 000.

PHOTO: ANDREW GOMBERT/CORBIS

reflections BY ROBERT W. LUCKY

The Elusive Future

WHY ARE we engineers so bad at making predictions?

In countless panel discussions on the future of technology, I'm not sure I ever got anything right. As I look back on technological progress, I experience first retrospective surprise, then surprise that I'm surprised, because it all crept up on me when I wasn't looking. How can something like Google feel so inevitable and yet be impossible to predict?

I'm filled with wonder at all that we engineers have accomplished, and I take great communal pride in how we've changed the world in so many ways. Decades ago I never dreamed we would have satellite navigation, computers in our pockets, the Internet, cellphones, or robots that would explore Mars. How did all this happen, and what are we doing for our next trick?

The software pioneer Alan Kay has said that the best way to predict the future is to invent it, and that's what we've been busy doing. The public understands that we're creating the future, but they think that we know what we're doing and that there's a master plan in there somewhere. However, the world evolves haphazardly, bumbling along in unforeseen directions. Some seemingly great inventions just don't take hold, while overlooked innovations proliferate, and still others are used in unpredicted ways.

THE PICTUREPHONE, shown here in 1965, flickered and died in the marketplace.

PHOTO: BETTMANN/CORBIS

When I joined Bell Labs, so many years ago, there were two great development projects under way that together were to shape the future—the picturephone and the millimeter waveguide. The waveguide was an empty pipe, about 5 centimeters in diameter, that would carry across the country the 6-megahertz analog signals from those ubiquitous picturephones.

Needless to say, this was an alternative future that never happened. Our technological landscape is littered with such failed bets. For decades engineers would say that the future of communications was video telephony. Now that we can have it for free, not many people even want it.

The millimeter waveguide never happened either. Out of the blue, optical fiber came along, and that was that. Oh, and analog didn't last. Gordon Moore made his observation about integrated-circuit progress in the midst of this period, but of course we had a hard time believing it.

Analog switching overstayed its tenure because engineers didn't quite believe the irresistible economics of Moore's Law. Most engineers used the Internet in the early years and knew it was growing at an exponential rate. But, no, it would never grow up to be a big, reliable, commercial network.

The irony at Bell Labs is that we had some of the finest engineers in the world then, working on things like the integrated circuit and the Internet—in other words, engineers who were responsible for many of the innovations that upset the very future they and their associates had been working on. This is the way the future often evolves: looking back, you say, "We should have known" or "We knew, but we didn't believe." And at the same time we were ignoring the exponential trends that were all around us, we hyped glamorous technologies like artificial intelligence and neural networks.

Yogi Berra, who should probably be in the National Academy of Sciences as well as the National Baseball Hall of Fame, once said, "It's tough making predictions, especially about the future." We aren't even good at making predictions about the present, let alone the future.

Journalists are sometimes better than engineers about seeing the latent future embedded in the present. I often read articles telling me that there is a trend where a lot of people are doing this or that. I raise my eyebrows in mild surprise. I didn't realize a lot of people were doing this or that. Perhaps something is afoot, and an amorphous social network is unconsciously shaping the future of technology.

Well, we've made a lot of misguided predictions in the past. But we've learned from those mistakes. Now we know. The future lies in quantum computers. And electronics will be a thing of the past, since we'll be using optical processing. All this is just right around the corner. ❑

JAN MAMMEY/GETTY IMAGES

The Biggest Career Choice Of All Is When to Start

Grad school may cost you more than you think

YOU'RE A COLLEGE SENIOR, a few exams away from that engineering diploma, and you have to decide whether to take a job or go to graduate school. To choose wisely you must estimate the likely economic return on your investment.

It's not an easy calculation. The details will differ from place to place, school to school, and person to person. To simplify things, we'll use average U.S. costs and benefits.

Let's look first at the benefits of a graduate degree. In 2007, a new master of science in electrical engineering graduate earned more than US $66 000, compared with about $55 000 for bachelor's degree recipients, according to the National Association of Colleges and Employers in Bethlehem, Pa. The extra bump from a doctorate was about the same: in 2007 new Ph.D. salaries averaged almost $76 000.

For those with graduate degrees, the good news only gets better over time, because salaries for those with grad degrees rise more and for a longer period. That might make you believe that getting an advanced degree is a no-brainer.

Not so. Even the most bare-bones calculation needs to include three additional factors—the cost of tuition, the cost of not working, and the value of money. Tuition for graduate studies averages $24 000 a year at a public university, according to the National Science Foundation's latest report, "Science and Engineering Indicators 2008." Not working for a year costs you on average $55 000 (before taxes). And a dollar you spend today is worth a lot more than one you will earn decades from now, given both inflation and the real rate of return on investments.

"A doctorate is very expensive for someone in electrical engineering because of the earnings they would have to forgo while in grad school," says Mark Regets, at the NSF's division of science resources statistics. When you look back at four or five years in grad school, you might assess the final cost at $1 million.

Mercifully, engineering graduate students do well when it comes to financial support in the form of research assistantships, teaching assistantships, and fellowships. All in all, engineering and computer science doctorate recipients were the least likely to report both debt and high levels of debt, according to the NSF report.

Some benefits are harder to translate into dollars and cents. The biggest return is career flexibility, says Regets. "You have more choices as to what you do, you have more choices over your conditions of employment, you're less likely to end up on the lower end of the earnings distribution," he says.

Higher degrees can bring job security in a shaky economy. In the shadow of the 2001 dot-com bust, the job market was toughest for electrical engineers and computer scientists. Unemployment for bachelor's degree holders hovered around 5 percent, almost twice the rate as for Ph.D.s.

Grad school specialization also gives you an edge. Fast-paced changes in technology push companies to look for skills that cannot be acquired in a bachelor's program. Texas Instruments now hires six times as many engineers with master's degrees or higher as it did a decade ago.

Whether or not to go to graduate school is, in the end, a personal choice. Megan McGinty, who graduated this summer from Valparaiso University with a bachelor's in EE, says she had planned to get a master's degree but decided to start working full-time. "Of course, earning a salary is going to be nice, but I don't think this would have stopped me from attending grad school," she says. She chose work in order to gain time to think about which area of specialization she wants to pursue. As an added bonus, her current employer will pay for her master's degree.

—PRACHI PATEL-PREDD

Extremist Engineers

Why are so many jihadis engineers?

WHICH ACADEMIC pursuit has been the most prevalent among Islamic jihadis?

It's not the oddest question to come up at a dinner party, especially at the University of Oxford. But when it comes up between a Middle East expert and a sociologist, idle talk yields to a quest for data. That's how political scientist Steffen Hertog and sociology professor Diego Gambetta soon found themselves poring through records of 404 people from 30 countries engaged in political violence between 2005 and 2007. Their answer? Engineering.

Of the 178 whose academic focus could be ascertained, 44 percent of those were engineers—most of them in electrical engineering, civil engineering, and computer studies. The next-largest group, Islamic studies, had fewer than half as many, at 19 percent [see table, "Fields of Study"].

The authors acknowledge that the data underrepresent groups in South Asia, Southeast Asia, North Africa, and Iraq. They claim, though, that the sample population is "disparate enough—there are individuals from 30 nationalities, nine larger groups, and no fewer than a dozen smaller groups—to allow us to establish whether the puzzle holds true."

FIELDS OF STUDY	
Engineering	78
Islamic studies	34
Medicine	14
Business/economics	12
Sciences	7
Education	5
Other	28
Subject unknown	18
Total	**196**

Source: "Engineers of Jihad," by Diego Gambetta and Steffen Hertog, *Sociology Working Papers*, paper number 2007-10, University of Oxford.

The findings garnered worldwide attention when they were published online last fall in a 90-page working paper. A catchy title didn't hurt: "Engineers of Jihad."

Hertog, now a lecturer in political economy at the University of Durham, in England, says that though he and Gambetta expected the paper to get noticed, they were surprised by accusations of "ethnic profiling."

"After all, the anecdote that engineers were overrepresented in radical Islamic movements in the Middle East has been around for decades," Hertog says. "But there was never a systematic study about how many were involved in political violence or radical Islam."

Curiously, the two have not heard from Islamists themselves. "Frankly, we hope we don't, after what the engineers said," Hertog adds. "Some of them were generally curious. But most had knee-jerk reactions. Look, we did not say engineers have a terrorist mind-set—please write that. We said that engineers tend to be politically to the right and more conservative than other graduates. You can therefore infer that their radical fringe is closer to those of religious groups."

Hertog and Gambetta believe that a combination of social conditions and an engineering mind-set make engineers susceptible to radicalization.

The paper cites evidence that engineering graduates are much more religious and politically conservative than those pursuing other courses

BRIAN STAUFFER

of study. "People gravitating toward engineering already have those views," says Hertog. "Engineering seems to attract a larger share of people drawn to rule-bound systems, compared with other scientists who primarily work on open-ended questions and might be more skeptical."

The paper suggests that the trend is also driven by professional disenfranchisement. "The effect of the lack of opportunities was intensified by the corrupt, state-driven job allocation," the researchers wrote. In other words, Hertog says, after having earned an elite degree you're frustrated having to drive a taxi or sell vegetables, just because you lack powerful friends.

Hertog and Gambetta are planning to expand their findings into a book covering the topic in far more detail, with more anecdotes, background information, and data from 600 case files recently found by American forces in a jihadist hideout in Iraq. It will include additional survey data on political and religious attitudes of engineers in developing countries and the Muslim world and locate their findings more broadly in theories of political violence, radical behavior, and cognitive psychology studies on how personality traits relate to political attitudes. It will then link those findings to studies of how small radical groups form and consider why certain individuals are more likely to be involved.

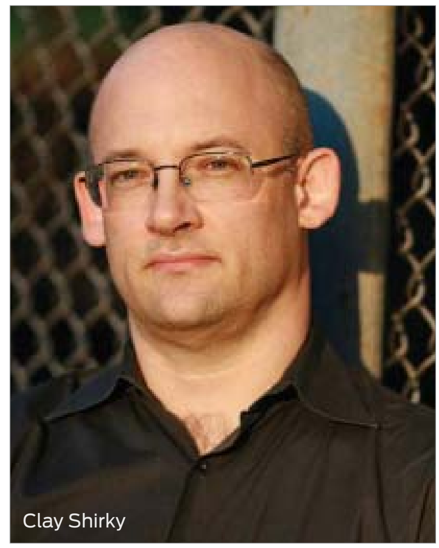
"Looking back, we never should have put the paper on the Web," says Hertog. "It put us on the map, but not in the way we wanted to be." —SUSAN KARLIN

LIA BULAONG

books

Here Comes *Here Comes Everybody*

Clay Shirky's new book explains how the Internet makes silly organizations possible


Clay Shirky

IN 1937, Ronald Coase answered one of the most perplexing questions in economics: if markets are so great, why do organizations exist? Why don't people just buy and sell their own services in a market instead? Coase, who won the 1991 Nobel Prize in Economics, answered the question by noting a market's transaction costs: buyers and sellers need to find one another, then reach agreement, and so on. The Coase theorem implies that if these transaction costs are low enough, direct markets of individuals make a whole lot of sense. But if they are too high, it makes more sense to get the job done by an organization that hires people.

Economists have long understood the corollary concept of Coase's ceiling, a point above which organizations collapse under their own weight—where hiring someone, however competent, means more work for everyone else than the new hire contributes. Software projects often bump their heads against Coase's ceiling: recall Frederick P. Brooks Jr.'s seminal study, *The Mythical Man-Month* (Addison-Wesley, 1975), which showed how adding another person onto a project can slow progress and increase errors.

What's new is something consultant and social technologist Clay Shirky calls "Coase's Floor," below which we find projects and activities that aren't worth their organizational costs—things so esoteric, so frivolous, so nonsensical, or just so thoroughly unimportant that no organization, large or small, would ever bother with them. Things that you shake your head at when you see them and think, "That's ridiculous."

Sounds a lot like the Internet, doesn't it? And that's precisely Shirky's point. His new book, *Here Comes Everybody: The Power of Organizing Without Organizations*, explores a world where organizational costs are close to zero and where ad hoc, loosely connected groups of unpaid amateurs can create an encyclopedia larger than the *Britannica* and a computer operating system to challenge Microsoft's.

Shirky teaches at New York University's Interactive Telecommunications Program, but this is no academic book. Sacrificing rigor for readability, *Here Comes Everybody* is an entertaining as well as informative romp through some of the Internet's signal moments—the Howard Dean phenomenon, Belarusian protests organized on LiveJournal, the lost cellphone of a woman named Ivanna, Meetup.com, flash mobs, Twitter, and more—which Shirky uses to illustrate his points.

The book is filled with bits of insight and common sense, explaining why young people take better advantage of social tools, how the Internet affects social change, and how most Internet discourse falls somewhere between dinnertime conversation and publishing.

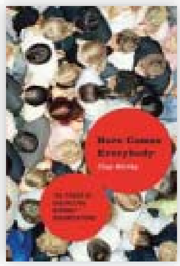
Shirky notes that "most user-

books

generated content isn't 'content' at all, in the sense of being created for general consumption, any more than a phone call between you and a sibling is 'family-generated content.' Most of what gets created on any given day is just the ordinary stuff of life—gossip, little updates, thinking out loud—but now it's done in the same medium as professionally produced material. Unlike professionally produced material, however, Internet content can be organized after the fact."

No one coordinates Flickr's 6 million to 8 million users. Yet Flickr had the first photos from the 2005 London Transport bombings, beating the traditional news media. Why? People with cellphone cameras uploaded their photos to Flickr. They coordinated themselves using tools that Flickr provides. This is the sort of impromptu organization the Internet is ideally suited for. Shirky explains how these moments are harbingers of a future that can self-organize without formal hierarchies.

These nonorganizations allow for contributions from a wider group of people. A newspaper has to pay someone to take photos; it can't be bothered to hire someone to stand around London underground stations waiting for a major event. Similarly, Microsoft has to pay a programmer full time, and *Encyclopedia Britannica* has to pay someone to write articles. But Flickr can make use of a person with just



HERE COMES EVERYBODY: THE POWER OF ORGANIZING WITHOUT ORGANIZATIONS
By Clay Shirky; Penguin Press, 2008; 336 pp.; US $25.95; ISBN: 978-159420153-0

one photo to contribute, Linux can harness the work of a programmer with little time, and Wikipedia benefits if someone corrects just a single typo. These aggregations of millions of actions that were previously below the Coasean floor have enormous potential.

But a flash mob is still a mob. In a world where the Coasean floor is at ground level, all sorts of organizations appear, including ones you might not like: violent political organizations, hate groups, Holocaust deniers, and so on. (Shirky's discussion of teen anorexia support groups makes for very disturbing reading.) This has considerable implications for security, both online and off.

We never realized how much our security could be attributed to distance and inconvenience—how difficult it is to recruit, organize, coordinate, and communicate without formal organizations. That inadvertent measure of security is now gone. Bad guys, from hacker groups to terrorist groups, will use the same ad hoc organizational technologies that the rest of us do. And while there has been some success in closing down individual Web pages, discussion groups, and blogs, these are just stopgap measures.

In the end, a virtual community is still a community, and it needs to be treated as such. And just as the best way to keep a neighborhood safe is for a policeman to walk around it, the best way to keep a virtual community safe is to have a virtual police presence.

Crime isn't the only danger; there is also isolation. If people can segregate themselves in ever-increasingly specialized groups, then they're less likely to be exposed to alternative ideas. We see a mild form of this in the current political trend of rival political parties having their own news sources, their own narratives, and their own facts. Increased radicalization is another danger lurking below the Coasean floor.

There's no going back, though. We've all figured out that the Internet makes freedom of speech a much harder right to take away. As Shirky demonstrates, Web 2.0 is having the same effect on freedom of assembly. The consequences of this won't be fully seen for years.

Here Comes Everybody covers some of the same ground as Yochai Benkler's *Wealth of Networks*. But when I had to explain to one of my corporate attorneys how the Internet has changed the nature of public discourse, Shirky's book is the one I recommended.

—Bruce Schneier

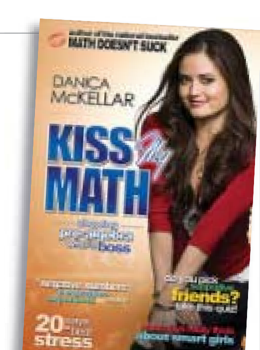
Math Kisser

Actress-mathematician-author Danica McKellar has a new book out called *Kiss My Math: Showing Pre-Algebra Who's Boss*, encouraging math interest in middle school girls. Best known as Winnie Cooper in the 1988–1993 TV series "The Wonder Years," McKellar went on to major in math at UCLA, collaborate on a theorem on magnetism, and speak before the U.S. Congress, while guest-starring on "The West Wing," "NYPD Blue," and "How I Met Your Mother." The new book, a continuation of her preteen best seller *Math Doesn't Suck*, focuses on pre-algebra and jobs that use math. "I'm making girls feel less intimidated by math," says McKellar. "I want them thinking about it as more than just something you do in school."

For more information, visit http://www.kissmymath.com. And read more about McKellar this December in the upcoming issue of *IEEE Women in Engineering Magazine*.

—Susan Karlin

KISS MY MATH: SHOWING PRE-ALGEBRA WHO'S BOSS
By Danica McKellar; Hudson Street Press, 2008; 352 pp.; US $24.95; ISBN: 978-159463049-1



tools&toys

The Voltage in the Dell

A mysterious current led me to the perfect multipurpose monitor

I JUST CAN'T squeeze two screens into my living-room home office, sharing it as I do with two small boys, their train sets and games, and a tank full of aquatic frogs. So last year I sought out one display that would do everything. My seemingly simple search turned into an engineering detective story that would ultimately involve three companies, four monitors, a helpful executive, and a tutorial on the nature of electric current.

It wasn't much of a quest at first: I quickly settled on a US $999 27-inch Dell 2707WFP with decent resolution, which I could plug my digital cable box directly into. Then I noticed horizontal pink bands that moved slowly through the television picture. The problem stumped customer service at both Dell and Time Warner Cable. Still, Dell swapped the monitor three times. Time Warner changed my set-top box and then my cables. Nothing worked. It was time for Google.

I searched on "slow pink bars" and found my problem: a ground loop—the same condition that causes a loud hum in some stereo equipment. When there are small voltage differences in the wiring that connects different pieces of electrical equipment, an unintended current will flow through the system. In my case it ran through a printed circuit board within the monitor, showing as slow-moving bands called hum bars, which are sometimes pink.

With my diagnosis, I also found Jensen Transformers, in Chatsworth, Calif., known throughout the Internet as the king of ground-loop fixers. Jensen sold me a $60 ground-loop isolator that attached to my television cable. It worked, but it also blocked the kids' cable cartoon channels. Jensen sent another model of isolator that had the same problem. Not giving up, the company sent—at its own expense—a $500 "humbucker." When that didn't work, Jensen's president, Bill Whitlock, called to take me on a step-by-step test to find the exact point in my system where the pink gremlins were invading. He also told me that a properly designed monitor would have routed the ground hum away from the video circuitry. Visible bars were evidence of what he called a "head-slapping design flaw."

Whitlock wondered aloud whether anyone teaches ground loops in engineering schools these days. Designers, he says, apparently come out of places like MIT thinking that ground wire equals zero current, end of story. Most designers don't know that they can build a $15 test device that would vastly improve their designs.

PINK HUM BARS, visible in the white lettering above, proved a nearly intractable problem in one Dell monitor model.

PHOTO-ILLUSTRATION: HUM BARS: BILL WHITLOCK; MONITOR: DELL

I called Dell once again. The company generously responded with an upgrade to a far better monitor—the 3008WFP, a 30-inch model that had come out just two weeks earlier and costs twice as much as my original. Its resolution is so good I can keep five or six windows open at once. It also doubles as a true HD 1080 television.

Last year, the only monitors with 4-megapixel (2560-by-1600) resolution were designed strictly for doctors and graphics artists. They were expensive, yet didn't easily replace a TV, having only a single digital visual interface (DVI) input. This year, however, Dell realized that a simple modification would make its highest-end monitor ideal for video gaming and plain old television watching as well as computing. Dell gave it seven inputs in all, including high-definition multimedia interface, display port, DVI, component video (the familiar triad of red, green, and blue plugs), and composite video (using a single yellow RCA connector). The picture is so crisp, and the colors so vivid, that the 3008 has become the kids' favorite set. In fact, they complain bitterly when Mom takes it back for her obsessive multitasking.

All this technology doesn't come cheap. The monitor itself costs about $1964, and for peak resolution you need a high-end graphics card. And this is, of course, television without a tuner and without built-in sound. Add a cable or satellite box and external speakers, though, and it's good to go.

Would I buy one next time around? For me the 3008 is absolutely worth the full freight. If a television is all you're looking for, you can get a 42-inch high-end set for the same money. But if you want one screen that does it all and does it very well, it's worth going into the red. Just stay out of the pink.

—SHERRY SONTAG

PART ONE OF A TWO-PART REPORT

Billions of dollars spent on defeating improvised explosive devices are beginning to show what technology can and cannot do for the evolving struggle

By Glenn Zorpette

COUNTERING IEDS

TWO PLATOONS OF U.S. ARMY SCOUTS are in a field deep in the notorious "Triangle of Death" south of Baghdad, a region of countless clashes between Sunni insurgents and Shia militias. The platoons are guided by a local man who's warned them of pressure-plate improvised explosive devices, designed to explode when stepped on. He has assured them that he knows where the IEDs are, which means he's almost certainly a former Sunni insurgent.

The platoons come under harassing fire. It stops, but later the tension mounts again as they maneuver near an abandoned house known to shelter al-Qaeda fighters. A shot rings out; the scouts take cover. They don't realize it's just their local guide, with an itchy trigger finger, taking a potshot at the house. The lieutenant leading the patrol summons three riflemen to cover the abandoned house.

Then all hell breaks loose. One of the riflemen, a sergeant, steps on a pressure-plate IED. The blast badly injures him, the two other riflemen, and the lieutenant. A Navy explosives specialist along on the mission immediately springs into action, using classified gear to comb the area for more bombs. Until he gives the all clear, no one can move, not even to tend the bleeding men. Meanwhile, one of the frozen-in-place scouts notices another IED right next to him and gives a shout, provoking more combing in his area. Then a big area has to be cleared so that the medevac helicopter already on the way can land. The sergeant dies several hours later in a field hospital.

EDITOR'S NOTE: To minimize the possibility that information in this article could endanger coalition personnel in Iraq or Afghanistan, a draft of this article was reviewed by current and former officials of the Joint IED Defeat Organization, a U.S. Department of Defense agency. In response to those reviews, *IEEE Spectrum* voluntarily removed three passages and the names of two active-duty U.S. military personnel.

That incident, which took place on 7 November 2007, exhibits many of the hallmarks of the missions in Iraq and Afghanistan—a small patrol; a local man of dubious background; Navy specialists working with soldiers on dry land; and costly technologies pressed into service against cheap and crude weapons.

And, most of all, death by IED.

"Sergeant T" became one of the 24 coalition soldiers killed by IEDs that month in Iraq. As of the end of June, IEDs have killed untold thousands of Iraqis and Afghanis, as well as 1795 coalition military people in Iraq and another 231 in Afghanistan, according to the Web site iCasualties.org. Those figures are nearly half of all combat fatalities in Iraq and roughly 30 percent of those in Afghanistan, according to the site.

IED fatalities in Iraq were down sharply in May and June, to 14 and 11, according to iCasualties. But they were up in Afghanistan, to 12 in May and 22 in June. Overall, in the first half of this year, IEDs, including suicide bombs, killed 115 coalition people in Iraq and 72 in Afghanistan. Those figures mean that in the first half of 2008, IEDs caused 54 percent of all coalition deaths (including nonhostile ones) in Iraq and 59 percent in Afghanistan.

The U.S. military has responded with the most intensive program of technology development in at least a decade. It has spent US $12.4 billion over the past three years on counter-IED equipment, technology R&D, training, and other measures through the Joint Improvised Explosive Device Defeat Organization and its predecessors.

JIEDDO says that its mission is to support efforts to defeat IEDs as "weapons of strategic influence." This wording acknowledges that insurgent fighters use IEDs with no hope of defeating a military force in the traditional sense. The point is to cause death and destruction resulting in news imagery that affects the political will of the country that dispatched the force. This distinction is significant because it implicitly suggests that IEDs and the casualties they cause cannot be eliminated. It points to a response based on minimizing their effectiveness, for example with armor and by other means, to marginalize their strategic impact.

JIEDDO emphasizes a holistic approach, incorporating such nontechnical aspects as training troops in counter-IED tactics and technology and using law enforcement techniques, forensics, and intelligence to smash the networks that build and deploy IEDs. But this year, $2.57 billion of JIEDDO's $4.38 billion budget is devoted to developing counter-IED technologies, feeding a perception that the agency is chasing a cure-all.

In an interview, a civilian at a military academic institution who studies counter-IED tactics characterized the U.S. approach as "hide and pray: hiding behind more armor and praying that there's a technical solution to all this."

Three U.S. military officers offered more specific criticisms in a recent paper for the Joint Forces Staff College, in Norfolk, Va. JIEDDO, they wrote, "is still built around a technical-solution approach focused on research and development, testing, and fielding the elusive 'silver bullet' to defeat IEDs."

There are lots more published criticisms in that vein. Nevertheless, it's basically impossible to find anyone inside or outside of JIEDDO who believes in a "silver bullet" technology that will solve the IED problem. On the other hand, it's not too hard to find people who think that technologies—including ones that predict or detect IEDs as well as others that neutralize them or at least lessen their effects—will be *part* of a complicated and variable set of responses that reduce the lethality of IEDs and also increase their costs to the extent that they become ineffective.

The challenge is more complex than most people realize. "There have been no easy problems when it comes to measure-countermeasure, whether you're talking about submarine warfare–antisubmarine warfare, tank-antitank, or antiaircraft-counterantiaircraft," says Daniel Gouré, vice president of the Lexington Institute, an Arlington, Va., think tank. "They're always immensely complicated challenges in which technology just plays a piece.

PREVIOUS SPREAD: ZORIAH

RIGHT OF BOOM: ***Jose Callazo's Husky mine-detecting vehicle hit a buried IED south of Baghdad on 4 August 2007. Callazo was treated by medics [far left] and recovered from his injuries. A vehicle-borne IED outside a newspaper office in Baghdad's Waziriya district [center] killed two people, injured 30, and destroyed more than 20 cars. A soldier paid tribute [above] in 2006 to a comrade killed by an IED.***

PHOTOS, FROM LEFT: BENJAMIN LOWY/VII NETWORK; ELI J. MEDELLIN/U.S. NAVY; PETER VAN AGTMAEL/MAGNUM PHOTOS

"Overall," Gouré adds, "the effort to counter the IED has been a real lesson in humility to a military that has always prided itself on being able to find a technical solution to a problem."

The U.S. experiences in Iraq and Afghanistan have pretty much confirmed that technology alone can't solve an IED problem. U.S. forces did not see steep declines in IED incidents in parts of Iraq until they gained the cooperation of local people in those areas and secured their help in aggressive efforts to attack the terrorist networks that put IEDs on the roads.

The problem is that in war or its aftermath, the active support of local people can seldom be counted on. And IEDs are already a problem in places where there is no occupation, where no war is being fought, and where there is no antagonistic local population to be won over.

It's not easy to assess counter-IED technology's capabilities and limits, because researchers are pursuing hundreds of projects, many of them are classified, and some have yet to prove themselves outside of a laboratory. Nevertheless, with the United States and other countries pouring billions of dollars into counter-IED activities, a couple of questions come to mind: how much can technology do, in the absence of local cooperation, to reduce casualties from IEDs? Can some combination of the technologies now being pursued, together with nontechnical approaches such as intelligence exploitation, suffice to marginalize the strategic influence of IEDs?

The alternative scenario is not pretty. In it, the IED continues for the foreseeable future to be the weapon of choice for the world's terrorists, insurgents, militias, guerillas, revolutionaries, and marginal or failed states.

THE STAKES ARE HIGH. The scale and urgency of the struggle to devise an effective response reflects not just the deaths in Iraq and Afghanistan but also an almost universal consensus among military analysts and government officials that the IED problem will long outlive those conflicts. Lots of facts support that view, but start with this one: *outside* of Iraq and Afghanistan, there are 200 to 350 IED attacks every month around the world, according to the Triton report, which is published periodically by the British counter-IED consulting firm Hazard Management Solutions. IED attacks are particularly common in Colombia, India, Indonesia, Pakistan, the Philippines, Russia (Chechnya), and Sri Lanka.

In Pakistan alone, IEDs, including suicide bombs, killed 865 security people and officials last year, according to testimony in the U.S. Senate in February. In 2006, British officials dealt with 250 IEDs in the UK, according to Andy Trotter, deputy chief constable of the British Transport Police. They were planted by "criminals, animal rights activists, disturbed individuals, and terrorists," Trotter says.

IEDs aren't new. In World War II, Belorussian guerillas used them against the German army. The Vietcong made them out of unexploded U.S. ordnance during the Vietnam War. The mujahideen used IEDs in Afghanistan in the 1980s against the Soviets.

But it was the Irish Republican Army that first demonstrated the level of havoc that homemade bombs could create in a sustained campaign. Over 37 years, from the early 1970s until the late 1990s, the IRA targeted infrastructure and British soldiers and achieved "a complete spectrum of development of the IED from simple, crude devices to quite sophisticated devices," says Lt. Col. Jim Storr, a British Army veteran. In the early 1970s, the British Army was dealing with as many as 1400 IED detonations a year, Storr says.

That's how many occur in Iraq and Afghanistan in three or four months.

The prevailing theory on the future of warfare contends that recent and ongoing conflicts—in Afghanistan, Bosnia, Iraq, Israel, Lebanon, Sudan—are just the opening phases of what will be a decades-long era of scattered, low-intensity engagements that will pit advanced countries against a constantly changing assortment of nonstate militias and marginal or failed states. The conflicts will be "asymmetric," meaning that the fight-

ing won't involve vast arrays of tanks, fighter planes, and bombers, radar and countermeasures, and troops firing ordnance at each other in accordance with military doctrine as it has evolved over the past 2500 years. Given their goals and the means available to them, and their need to counteract their opponents' overwhelming advantages in technology and resources, insurgents and militiamen will keep on using IEDs, including car and suicide bombs.

To be specific: "The IED threat will be long-term, because nobody will want to fight the United States force-on-force," predicts Col. Dick A. Larry, head of the IED division of the U.S. Army Asymmetric Warfare Office.

"IEDs have the capability to inflict damage, political and psychological, out of all proportion to their size and cost," noted Maj. Gen. Anthony Stone, the former director of special projects for the UK's Ministry of Defense, at a recent conference on counter-IED technology.

Some analysts warn that rogue fighters will inevitably use weapons of mass destruction, probably in an improvised way. And though the United States and some European and Asian countries have seen few IED attacks so far, not many analysts think that state of affairs will go on indefinitely.

"If we do not find solutions now in Afghanistan and Iraq, we will continue looking for solutions when this problem comes to the United States," says Colonel Barry L. Shoop, who is director of the electrical engineering program at the U.S. Military Academy and was JIEDDO's first chief scientist.

The difficulty of the counter-IED challenge arises from many factors. The physical, electromagnetic, and chemical environments in which IEDs are deployed are chaotic and cluttered. The social networks that let insurgents fund, build, and emplace IEDs are incredibly complex. And IEDs themselves are hugely diverse, their makers having proved themselves tireless in adapting and altering their creations.

All IEDs have a power source, a trigger, a detonator, and a main charge. The power source is usually a battery. Its function is to supply enough energy to the detonator, usually a blasting cap, to enable it to set off the main charge. In 2004, as IEDs began proliferating wildly in Iraq, the main charge was typically artillery rounds lashed together to explode simultaneously, the casings shattering to provide shrapnel. Bomb makers also frequently pack ball bearings around the main charge to maximize casualties.

Over the past couple of years, Sunni insurgents have favored homemade explosives for the main charge. They're more easily used in the huge quantities needed to fling through the air the 25-ton vehicles now commonly used by U.S. forces. The typical homemade explosives in Iraq, urea nitrate and ammonium nitrate, are produced using nitrogen-based fertilizers. To make urea nitrate, bomb makers separate the urea from the fertilizer and then use nitric acid to attach a nitrate group (NO_3) to the urea molecule.

The fertilizers and other materials are not easily controlled, because Iraq's struggling economy has a large agricultural component. And even with hundreds of IED incidents a month in Iraq, the relative amount of fertilizers diverted to making IEDs is small.

Five-gallon cans or barrels are common containers for the main explosive. For a barrel, the detonator might be a bag filled with TNT and a blasting cap (ironically, the bag has often been the thick plastic bag that a military "meal, ready to eat" comes in). To complete the IED, a trigger of some sort is connected to the detonator. Such a bomb could easily destroy a light vehicle like a Humvee or could seriously damage a heavier, more extensively armored vehicle, such as an MRAP (mine-resistant, ambush-protected) truck.

The two most lethal forms of IEDs are deep-buried IEDs and explosively formed penetrators (EFPs). They account for only 5 to 15 percent of all IEDs in Iraq but roughly 40 percent of the IED casualties, according to the latest figures from the U.S. Defense Department. Deep-buried IEDs often contain hundreds of kilograms of explosive and have flung heavily armored vehicles like MRAPs tens of meters, in one case killing all on board.

WE WENT into an intersection, and the EFP went off and went right through our vehicle," says the deputy commander of the Gulf Region Central District of the U.S. Army Corps of Engineers in Iraq. At the time of the attack, he was south of Baghdad, in a heavily armored vehicle called a Wolf. "The molten metal came up underneath us, and

BOMB-MAKING MATERIALS: *A tip in March 2007 led Iraqi police to a cache of IED-making parts in Anbar province. U.S. soldiers inspected the haul [far left], which included bags of blasting caps. An Iraqi Army raid turned up other IED items [center], including wires for triggering bombs at a distance. In February 2007 [right], U.S. soldiers found copper liners and enough other components to make 150 explosively formed penetrators, a particularly deadly form of IED. The materials were found in a Shia village north of Baghdad.*

PHOTOS, FROM LEFT: EROS HOAGLAND/REDUX; ZORIAH; ROBERT NICKELSBERG/GETTY IMAGES

there were a few shrapnel pieces that were inside the compartment. But, for the most part, it missed us." Even so, he was bleeding internally so badly that he had to be flown to Germany, where his life was saved by an 8-hour operation that put in 600 internal stitches. It was the fifth IED attack he'd survived, and by far the worst.

It was a classic explosively formed penetrator attack: the target was an armored vehicle, and the projectiles were fired at close range, in this case from below the vehicle.

EFPs are associated particularly with Shia militia groups. The U.S. military has long contended that Iran is a supplier of the EFP's key component—a concave copper disk, called a liner, that must be properly machined to work well. This disk is fitted to one end of a metal tube that's slightly longer than the diameter of the disk. The tube is packed with a plasticized military explosive, typically one containing cyclotrimethylenetrinitramine, also known as RDX. Its detonation releases an extremely fast-moving shock wave, which turns the liner into hot, explosively formed fragments moving at one to two kilometers per second—faster than a high-velocity rifle round. The kinetic energy of the fragments is so high that it penetrates most kinds of armor.

EFPs are usually triggered by a passive infrared sensor. The triggering system also often has a radio-control override that lets the triggerman enable the system when he sees a vehicle coming that he wants to attack. The infrared sensor then detects the heat of the passing vehicle and detonates the device. The U.S. military has contended that the radio-control systems also come from Iran.

The EFP is a textbook case of measure–countermeasure–counter-countermeasure. For a time, coalition vehicles sought to throw off the EFP's infrared trigger with a simple countermeasure called a rhino, basically a hot glow plug in a metal can affixed to the front of the vehicle by a rod of variable length. It reduced the effectiveness of EFPs but not decisively so, because the attackers varied the timing of the detonation to try to counteract the rhino.

The triggering system, generally the only complicated part of an IED, remains the focus of strenuous countermeasures because it is pretty much the only component you can attack with technology. Early on, in 2003 and 2004, most IEDs in Iraq and Afghanistan were triggered wirelessly, often with cellphones, long-range cordless phones, key fobs, walkie-talkies, and wireless doorbells.

Relying on modified existing hardware and Navy expertise, JIEDDO's predecessor quickly fielded jamming systems. Installed in vehicles, the jammers provide a bubble of safety around the vehicle, within which radio-frequency power overwhelms any signal being transmitted to an IED's wireless trigger.

The jammer program became known as CREW, for "counter radio-controlled IED electronic warfare." The latest jammers designed for U.S. vehicles are code-named Jukebox and CVRJ and are manufactured by EDO Corp. and other companies. They cost upwards of $80 000 apiece. All told, the U.S. military spent about $2 billion on jammers in 2007.

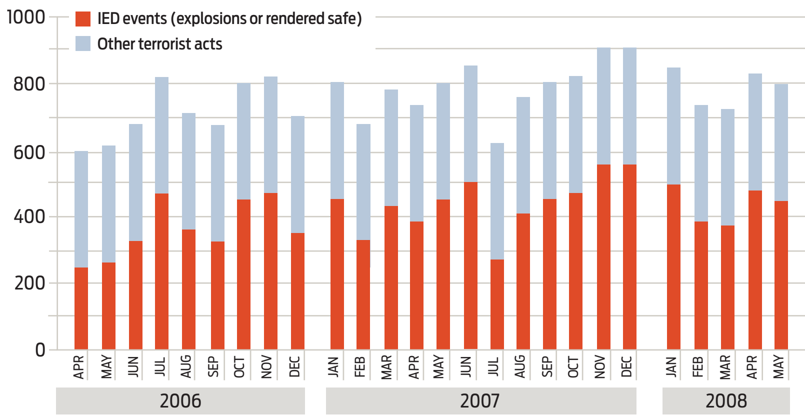
The insurgents' response to the first jammers, in late 2003, was swift. It established a *Spy vs. Spy*–like competition between counter-IED specialists and the bomb makers, in which sometimes a measure was followed by a countermeasure within days.

As jammers proliferated, insurgent groups quickly went back to using command wires—buried pairs of long enameled copper wires attached to a simple switch—and also to "victim-operated" triggers. These triggers, also usually buried for concealment, include pressure plates and crush wire—flexible tubing with two conductors inside that touch and make an electrical connection when the tubing is squashed by a tire or a foot.

"DEFEATING THE DEVICE" is how JIEDDO refers to the many things it does to deal with an IED already in place: searching for it, disposing of it, and if all else fails, surviving its blast. These tasks get a lot of attention because the score is easily tallied. Column A: lives

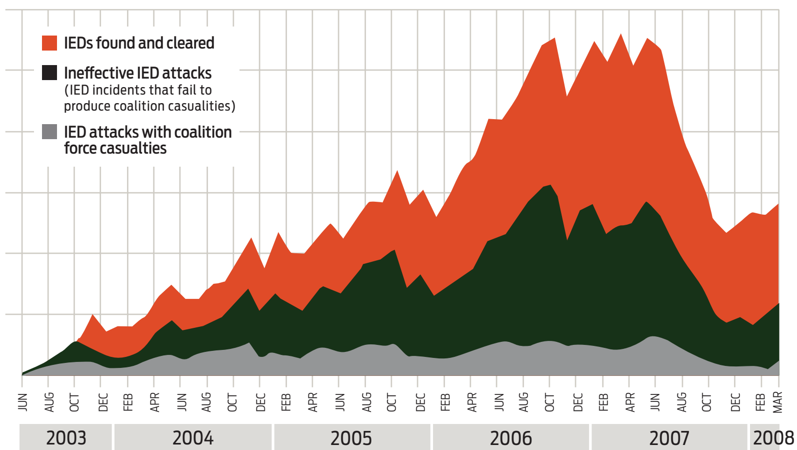
SPECTRUM Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page qMags

Monthly Global Terrorist Events (minus Iraq and Afghanistan)



Source: Triton Report

Iraq IED Incident Trends



Source: Joint IED Defeat Organization

IED ATTACKS *are already common in some places outside of Afghanistan and Iraq [top]. The rate of attacks in Iraq [bottom] declined in the first half of 2008, thanks to aggressive efforts to dismantle the networks that build and deploy IEDs. (The number of incidents is not included in this chart because the Joint IED Defeat Organization declined to release them.)*

saved; column B: lives lost, damaged, irrevocably changed. But defeating the device is actually a small piece of a much larger and evolving counter-IED strategy.

JIEDDO originally divided its projects among five functions: prediction, detection, prevention, neutralization (which includes defeating the device), and mitigation. Some of those technologies and most of the techniques, as deployed today in Iraq and Afghanistan, are classified. Still, what is known about those categories offers at least a partial view of evolving counter-IED strategies, as well as insights into the main issue: whether the strategic influence of IEDs can be subverted.

In this world, simply categorizing activities can be complicated. A few years ago, when it became clear that going after IEDs on the road wasn't having the desired effect, the rallying cry became "attack the network"—in other words, destroy the infrastructures that build and deploy IEDs. Attacking the network, it turns out, spans prediction, prevention, and part of detection.

JIEDDO has been criticized for spending too little on attacking the network. But as a former JIEDDO official wrote in an e-mail, "a significant portion of the activities in Attack the Network are classified," making it difficult for outsiders to know how big the effort actually is.

Attacking the network boils down in part to analyzing social networks, collecting and analyzing intelligence, and persistently surveilling places. It has been a difficult challenge, depending as it has on wildly incongruous data, tips, and reports from surveillance systems, such as unmanned aerial vehicles, and from local people suspicious of activity in their neighborhoods. "It's a challenging new frontier," says Shoop. "Combining an understanding of the psychology and sociology of terrorist networks with probabilistic modeling, complexity theory, forensic science, pattern recognition, and data mining to predict human behavior is new."

JIEDDO has already acknowledged that it is using sophisticated database software in Iraq to help its analysts get a handle on that multifarious assortment of images, data, intelligence, and anecdote that bears on whether an IED has been emplaced. In his final press conference this past November as director of JIEDDO, retired U.S. Army Gen. Montgomery Meigs identified for the first time an organization called the Counter IED Operations Integration Center. Calling it a "very powerful intelligence fusion operation," he added that "it makes a difference in that line of operations we call 'attack the network.' Beyond that, I can't say anything."

Meigs's successor at JIEDDO, Lt. Gen. Thomas F. Metz, said in an interview this past May: "Say you know a particular part of your district gets a larger proportion of IEDs. You want to study it, layer in all the data: signals intelligence, significant events over a couple years, moving target indicators from JSTARS [an advanced military reconnaissance aircraft], humint [human intelligence] reports. You have to take it on faith from me that actionable patterns begin to form."

LIFE AND DEATH on the roads of Iraq and Afghanistan often depend on the eyes and intuition of soldiers just a few years out of high school. Most IEDs are found today by a soldier peering through a thick Lexan window of a massively armored truck and noticing something amiss.

"You won't find the IED itself," explains a U.S. Army counter-IED trainer, in an interview at Camp Speicher in Tikrit, Iraq. "You look for other indicators. Trash right after a route clearance. Disturbed soil. An area strangely devoid of activity, or a heavily laden vehicle with no occupants. A donkey cart by itself—it's somebody's livelihood, so why is it abandoned? Why is no one there?"

Over the past year in Iraq, military patrols guided by local people, often former insurgents, have uncovered countless thousands of IEDs. The locals are paid to reveal where the bombs are.

Soldiers travel the roads in RG-31s, MRAPs, convoy trucks, and Buffaloes, which have a big robotic arm that can be operated from inside to paw through roadside junk. Many of the vehicles are also outfitted with a Gyrocam, a gyro-stabilized telescopic camera system that lets them scrutinize, on a monitor in the truck, suspicious roadside objects from hundreds of meters away. The system can be switched to one of three different bands: visible light, infrared, and thermal (the thermal mode is useful for turning up people hiding at night), and it costs more than $500 000. It is used on drone aircraft such as Predators as well.

Other technologies also help with detection. A vehicle called a Husky has a powerful magnetometer that detects buried metal-containing objects, such as pressure plates, crush wire, and artillery rounds. At the moment of detection, though, the driver is directly above the object. To protect the driver as much as possible in a blast, the Husky has a cast-metal suspension and a harness restraint system designed for a helicopter. Those features have let drivers walk away after being blown 20 meters in the air.

Drone aircraft also sometimes spot evidence of IEDs or even catch insurgents in the act of installing them. In tactical operations centers all over Iraq you can see video from Warrior, Shadow, Predator, or Hunter aircraft playing out on flat-panel monitors in real time. Mostly, the feeds show empty or cluttered roads and suggest the immensity of the detection challenge.

Nevertheless, a special C-IED U.S. Army task force called ODIN (for observe, detect, identify, neutralize) has for more than two years been using a small fleet of piloted and drone aircraft to monitor the main supply routes in Iraq. A *New York Times* report in June said the task force had about 300 people and 25 aircraft assigned to it. When they spot people placing IEDs, ground controllers feed the information to quick-response combat teams, with often fatal results for the bombers.

In an interview with the newsletter *Defence Systems Daily* last November, Maj. Gen. James E. Simmons said that as of August 2007 the program had resulted in the deaths of 233 IED emplacers, the injury of 48 others, and the detainment of 260. To put those numbers in perspective, in a typical month a single turbulent province like Salah Ad Din could, until recently anyway, record more than 800 IED incidents.

For the record, most of the armored vehicles listed above, as well as the Gyrocam and ODIN, were all at least partially funded initially by JIEDDO.

"IT'S REALLY HARD to find tiny wires in the dirt," said General Meigs in his final JIEDDO press conference last November. "And it's hard to find an IED that's buried. Those are tough challenges from a laws-of-physics perspective."

Tough, but maybe not impossible. Dozens of advanced-tech projects are aimed at detecting buried IEDs. Some systems are intended to fly aboard drone aircraft, others to be carried on vehicles; still others are to be carried by a soldier. In the airborne category are advanced imaging systems that would find buried IEDs, pressure switches, and even command wires by detecting disturbed earth. These systems, being developed by several defense contractors, would sense radiation in dozens of narrow spectral bands in the visible and infrared parts of the spectrum.

The principle is that disturbed earth scatters radiation differently from undisturbed earth. The system, called a hyperspectral imager, would run algorithms to calculate the signal strength in those spectral bands. That data would be used to map, for a grid of points on the ground, the reflectance as a function of wavelength. Limited processing power forces a tradeoff between the spatial resolution on the ground (you want to be able to see command wires) and the spectral resolution (you need a certain minimum number of spectral bands to reliably detect disturbed earth). The systems being tested now use bright, contrasting colors to show subtle differences in reflectance.

Another project, now being tested, detects command wires using a radio transmitter, carried by a soldier, that sweeps through a wide band of frequencies. The waves are polarized, and when the polarization is properly aligned with a length of buried wire, the radio-frequency energy couples into the wire. That coupling causes a resonance at a specific frequency. The system detects that resonance, which can indicate not only the presence of the wire but also its approximate length.

Troops are also testing detection systems that use ground-penetrating radar or other technologies to detect command wires. JIEDDO has publicly identified two such projects, code-named Desert Owl and Copperhead, but has not released any details.

There is also a lot of work on systems that can detect IEDs at what are called standoff distances: tens of meters, or far enough to survive if the IED blows up. A couple of years ago troops in Iraq were reportedly using a system called PING, which emitted microwave signals that penetrated building walls. If the signals encountered an IED with large amounts of metal, the IED altered those signals in a way that could be detected, presumably with reasonable consistency.

Some of these standoff systems depend, or will depend, on radically new technologies, such as terahertz-frequency and millimeter-wave radiation [see Web-only sidebar "Terahertz Waves: No Silver Bullet" at http://www.spectrum.ieee.org//sep08/ciedextra], or on radical applications of existing technology. Several have already been deployed, with limited success, but most are more than a few years away. The existing technologies include visible light lasers, ground-penetrating radar, synthetic-aperture radar, thermal imaging, magnetic resonance, and electronic "sniffers" that can detect in the air infinitesimal concentrations of molecules from explosives.

A sniffer called Fido is being used in Iraq and Afghanistan; there's a handheld version and also one attached to a small robot. Fido exploits a kind of material called an amplifying fluorescent polymer. A polymer is a long chain of identical molecular links called monomers. When a photon hits a fluorescent polymer, it releases an excited electron that travels along the chain, causing the monomers to fluoresce. The monomers are designed, however, so that if any one of them encounters and binds with a certain molecule—let's say one from a nitroaromatic explosive—the fluorescence is quenched.

Because the chain has so many potential receptor sites, the system based on it can detect concentrations down in the parts-per-quadrillion range, according to the original paper on the invention, which was published in the June 2001 *IEEE Transactions on Geoscience and Remote Sensing*. But although the Fido system works well, it does so only for a limited number of explosives, according to an official familiar with it. And the only standoff capability you get is from the robot.

NEUTRALIZING an IED means either disabling it or destroying it. Both jobs are performed by military specialists trained in the rapidly expanding discipline known as explosive ordnance disposal, or EOD.

U.S. EOD teams travel in 26-ton technology-stuffed trucks called Joint EOD Rapid Response Vehicles (JERRVs) that cost more than $1.2 million fully equipped (the JERRV was also a JIEDDO project). The teams, usually made up of two or three people, strive to disable and recover unusual IEDs because of their intelligence value. Those recovered IEDs, as well as forensic evidence gathered at places where IEDs have detonated, are sent to a laboratory near Baghdad airport for analysis. IED specialists say that years of work at that lab have enabled them to know, in many cases, such details as exactly who built an IED and possibly where he built it.

If the IED isn't unusual, or if disabling it doesn't seem straightforward, the EOD technicians use special-purpose robots to place plastic explosives on it and blow it up. [In next month's issue, *IEEE Spectrum* will publish a companion article to this one, on EOD in Iraq.]

There are other ways to neutralize an IED. A type of "predetonator" used in Iraq emits a strong electromagnetic pulse that wrecks the integrated circuits in the cellphone or other appliance that triggers an IED. The pulse comes from a very high voltage capacitor discharging very suddenly. When its ICs are zapped, the trigger might "fail open"—with no explosion—or it might "fail closed," detonating the IED.

Inevitably, there has been a countermeasure, and a cheap one at that. "These are billion-dollar solutions with ten-cent countermeasures," says Daniel B. Widdis, an instructor at the Naval Postgraduate School, in Monterey, Calif., who did a tour as an electronic countermeasures specialist in Iraq. [*Editor's note:* In response to JIEDDO's request, *IEEE Spectrum* agreed not to disclose the countermeasure.]

More sophisticated predetonators are said to mimic the signals of the IEDs' triggering devices in order to set them off. In the typical case the triggering devices, and therefore the specific codes that will trigger them, are not known. In an interview published in the 3 September 2007 issue of *Aviation Week and Space Technology*, James M. Smith, the CEO of EDO Corp., said that the predet systems transmit sequences of codes very rapidly. When the right code comes up, the IED detonates. The technique doesn't work, however, if the code is long—say, 18 bits or more. There are simply too many possible combinations, Smith said.

In February, JIEDDO announced that it had canceled two big predetonator programs, code-named Alexis and Electra-C, on the grounds that the signals from those systems interfered with counter-IED jammers such as Duke. A third program, called Blow Torch, is ongoing.

An article in the 25 March edition of *The Scotsman* newspaper, which quoted only anonymous sources, said that U.S. forces in Iraq and Afghanistan were using specially equipped Vietnam-era EA-6B Prowler aircraft to clear roads for convoys by transmitting appropriate signals to predetonate IEDs. (The article said the sweeps are called courtesy burns.)

A former JIEDDO official points to a tempting but difficult challenge for future predetonators. "It would be a breakthrough if we could find a safe and effective way to predetonate blasting caps," he says. "To underline the difficulty, remember that industrial and military caps are designed to not react to the static electricity that creates lightning."

HOW DO YOU mitigate an IED blast? Today, mostly with armor. Over the past year and a half, contractors and soldiers have gone from 3-ton SUVs to 7.8-ton Revas, and from 5-ton Humvees to 25-ton MRAPs and JERRVs.

Of course, there are disadvantages. Tons of armor make vehicles too sluggish to speed away from an ambush. And simple physics and economics confirm that in an escalating contest between bombs and armor, it's much cheaper and easier to make bigger bombs than to try to shield against those bombs with more and more armor.

But armor isn't the only factor in the life-death equation. MRAPs and JERRVs are much higher off the ground than Humvees, and parts of their undercarriages are V-shaped. The V shape deflects the force of a blast under the vehicle outward, away from the vehicle. The increased height not only puts more distance between the passenger compartment and a bomb buried in the road, it also makes it more difficult for insurgents to target the passenger compartment with an explosively formed penetrator.

The first MRAPs were delivered to Iraq in January 2007; there are now more than 3200 of them in combat roles. There have been more than 150 IED attacks on MRAPs, the U.S. Defense Department says, which resulted in a total of eight deaths. All the fatal attacks involved either an EFP or a deep-buried IED. The Defense Department plans to spend $5.4 billion to buy 4000 more MRAPs, making this acquisition program the Pentagon's third largest (only missile defense and the Joint Strike Fighter are bigger).

Future combat trucks will mitigate blasts with more than simple armoring. Some of the competing designs for the Joint Light Tactical Vehicle, the MRAP's proposed more agile but no-less-blast-resistant successor, take inventive approaches. For example, to reduce the organ- and spine-crushing shock from a blast that comes from below, some JLTV designs suspend their seats from the ceiling, rather than bolting them to the floor.

"If I can vastly mitigate the effects of an attack, I would argue that that is defeating the IED, too," says the Lexington Institute's Gouré.

OVER THE PAST 5 years, during which the U.S. Department of Defense spent more than $13 billion on counter-IED efforts, the IED did in fact become less effective. But how much of that success is attributable to technology? And was the money well spent? The answers are elusive.

At the very outset of the IED problem in Iraq, in mid- to late 2003, with soldiers driving around in unarmored Humvees and contractors in unaltered SUVs, almost every IED attack caused a casualty. It now takes roughly six IED attacks to cause one coalition casualty, according to JIEDDO.

Slightly more than half of all IEDs are found and cleared without detonating, JIEDDO says. Of those that do detonate, roughly 40 percent of them cause no injuries. More heavily armored vehicles are behind that statistic. And the more technologically advanced JLTV promises further improvements in survivability.

There are other indications of progress. Insurgent groups typically pay people, usually freelancers who are just in it for the money, to emplace IEDs. Several years ago, the going rate was about $50 per IED. Today the rate is $200 outside Baghdad, and $400 to $500 inside Baghdad, according to a counter-IED training official in Iraq. The higher rates are believed to reflect, among other things, the increased risk and danger of the job.

IED AFTERMATH: ***A mine-resistant, ambush-protected truck hit a roadside bomb on an Al Talbiyah street in Baghdad on 19 June. The heavily armored vehicle was significantly damaged, but no one was hurt.*** PHOTO: PETROS GIANNAKOURIS/AP PHOTO

JIEDDO director Metz believes the factors behind that fee increase suggest that the IED problem is solvable and also indicate the way forward. "It's constant pressure put on those who emplace IEDs that will win the day," he says. "It's becoming a cost-ineffective and risky business to be in."

How much more can technology contribute to that solution? To explain a lull in IED activity in Iraq in early 2008, JIEDDO's most recent annual report pointed to several factors: the cooperation of thousands of "concerned local citizens" who helped coalition forces locate IEDs and IED-making resources; the military surge, which stabilized some convulsive areas by pouring troops into them; and military efforts against the networks and "event chains" that lead to IEDs on the roads. Less prominent in JIEDDO's list are technology-related factors, a fact expounded on by defense affairs writer Sharon Weinberger in a *Wired* blog that was subtitled in part "Tech barely a factor."

Few of the people in Iraq whose job it is to deal with IEDs would embrace that assessment. They wouldn't deny that it's their eyes and intuition, along with local intelligence, that uncover most IEDs. But traveling Iraq's roads regularly makes them more appreciative of things like jammers, Gyrocams, EOD robots, armor, infrared and other sensors, and useful intel distilled with the help of a computer program from maybe half a dozen sources.

Without a doubt, many big-budget projects and exotic technologies have fizzled or were quickly and cheaply countered by the insurgents. But that doesn't mean that some of the technologies under development now or deployed in secret aren't already working, or that others won't be part of a more effective set of responses in the next few years.

It doesn't even mean that pursuing each and every one of those ultimately unsuccessful projects was a mistake. "Defeating the system takes leadership," says Lt. Col. Jeremy G. Mansfield, director of Canadian Forces EOD. "That's why we pay the generals the big bucks. It takes risk. Some things are going to cost a lot of money, and they aren't going to work. Get over it."

The Lexington Institute's Gouré believes that a combination of technologies, including some yet to be fielded, along with more survivable vehicles, aggressive exploitation of intelligence, and adherence to good operational countermeasures (simply varying the routes taken on repeated missions, for instance) might get the rate of IED detonations down to 15 or 20 percent from the present 40. That might be good enough.

"You want to get to a rate that's tolerable for you but unacceptable to him," he says. "I suspect that's exactly how it will end."

And don't dismiss what's been achieved so far, Gouré says. With new tactics and technologies in both counter-IED and EOD, "the American military has invented, in about three or four years, a way of warfare that didn't exist before. That's lightning speed.

"Could they be less bureaucratic?" he asks. "Probably not. That's the way the system works." ❑

Engineering Spore

HOW WILL WRIGHT, CREATOR OF *THE SIMS*, GAVE LIFE TO HIS EVOLUTIONARY—AND REVOLUTIONARY—NEW GAME

By David Kushner

IT'S TIME TO MAKE A CREATURE. Let's start with its body. Stretch down a pair of legs and pull out two arms so that it looks long and lean. On one end of the body, pop on intelligent eyes behind large round glasses. Add a mop of peppery hair and a prominent nose and ears. Sprinkle on scruffy semibeard growth. Call it Will Wright.

Now put the creature in its habitat: the workspace of a computer game developer in Emeryville, Calif. Spread the studios of Maxis Software, which Wright cofounded in 1987, over the floors of two nondescript office buildings. Sprinkle the interior with dirt-encrusted mountain bikes leaning against cubicle walls and overgrown, pumpkin-orange beanbag chairs. Now surround Wright with others of his kind, hunched behind desks, typing at keyboards, PC monitors glowing.

The software engineers, artists, and others who work at Maxis, now owned by videogame giant Electronic Arts, have migrated here because Wright is a legend. Over the past two decades, the 48-year-old Wright, who studied architecture and mechanical engineering at Louisiana Tech University, has utterly transformed his industry with hits like *SimCity*, in which players build virtual towns, and the best-selling computer game franchise of all time, *The Sims*, in which players create virtual people and then watch them interact. In the process, Wright has helped forge a new, more toylike frontier in computer gaming, where the main goal is not so much to score points or kill bad guys but to create cool stuff.

The game they're working on this bright February day is called *Spore*, and it's the most ridiculously ambitious simulation game yet. Sure, there've been virtual worlds like *Second Life*, which let you customize your characters. In games like *Fable* and *Black & White*, the characters even evolve in appearance and reputation based on how the player defines them: the more evil your beast, for example, the more feared it becomes. *LittleBigPlanet*, an upcoming game from Media Molecule for Sony's PlayStation 3 game console, is built around player-made terrains and characters. But Wright's *Spore* is by far the boldest in terms of unleashing players' creativity. In *Spore*

PHOTO-ILLUSTRATION: SEAN McCABE; ORIGINAL PHOTO: RYAN ANSON/AFP/GETTY IMAGES

the players create life itself—starting with ooze-dwelling, one-celled creatures that learn, grow, and evolve into intelligent beings with advanced cultures and technologies, able to conquer their planets and outer space.

Computer gamers everywhere have eagerly awaited Wright's latest project since he began talking about it in 2000. *Spore* is finally due to be released this month, more than a year behind schedule. Wright attributes its recent delays to localization, the process of tailoring the game to different countries and languages. Others around the Maxis office cite the boss's high expectations. Wright concedes their point but shrugs it off.

"For games, it is a long time, but for me it's not a big deal," he says, sipping coffee in his cluttered corner office. "I'd rather spend a couple of extra years and have it be a big seller than short it by a year or two and have it be mediocre."

Spore is anything but. Other games may look and sound better, but few games are as original as this one. It offers players far more choice and open-ended play than any game before it. If *Spore* lives up to its creator's vision, it will likely be heralded as one of those milestones that redefines what a game can be—just as *Doom*, a first-person shooter game, pioneered fast-action multiplayer competition in 1993 and *Guitar Hero* delivered the thrill of music performance by introducing a guitar-shaped controller.

The anticipation—and pressure—is high. "I call Wright a genius because he truly is one of the most innovative developers out there," writes one gaming blogger. "*Spore*...is creating an entirely new genre."

THE GAME UNFOLDS through five stages, each of which riffs on an established genre of play. It starts, fittingly, in a two-dimensional world, with a single-celled organism that gobbles up microbes and plants to accrue DNA points. Once the spore collects enough DNA, an editing palette pops up that lets you design the next evolutionary stage of the creature's body. Your creature is then thrown into a three-dimensional environment where it must dodge predators and find a partner with which to reproduce. By the third stage, your creature is fully evolved and you switch to controlling its entire tribe, as you would in real-time strategy games like Electronic Arts' *Command & Conquer*.

Next up is the civilization phase, in which you can assemble vehicles and buildings to bring your tribe's city to life, in the spirit of *SimCity* or *Civilization*. If you succeed in conquering your planet and avoiding an enemy takeover, you graduate to the fifth and final level: outer space. Here the object is to fight off invaders and take over other planets.

Developing a game in which the players create all the key parts—the characters, buildings, and vehicles—poses an obvious conundrum: "There's no content," says Maxis technology fellow Chris Hecker. "Initially, the problem was, well, what is [*Spore*] supposed to be?"

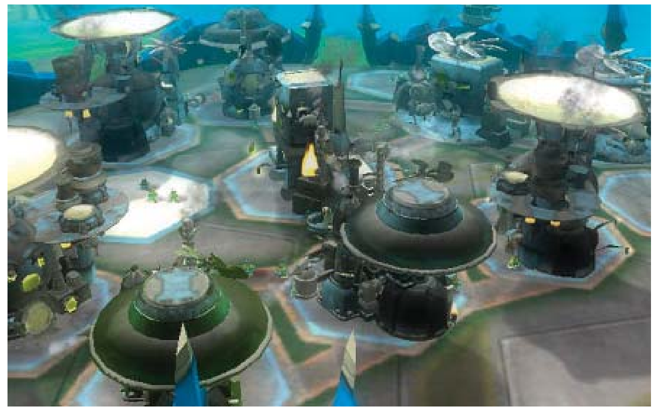
When you boot up most games for the first time, you're immediately immersed in an existing world, complete with a cast of characters who behave in predetermined ways. Perhaps the game has tree-lined streets or castles with dungeons and moats. Maybe colonies of dwarves and trolls populate those worlds, or maybe gangsters do. These objects are all encoded in the game's original software exactly as the developers envisioned and animated them.

In *Spore*, that model doesn't apply. Almost nothing exists until the player makes choices about each object's shape and texture. To enable that design process, the relatively small team of 20 artists and seven programmers created a palette of editing tools. They think of it as an "artist in a box" or, as Maxis software engineer Colin Andrews puts it, "Mr. Potato Head on steroids." Maxis released a stripped-down version of the tool palette, known as the Creature Creator, on 16 June to build buzz for the game. Eight days later, early adopters had created more than a million creatures.

To understand why the Creature Creator is so compelling, consider its incredible flexibility. Say a player wants to make a building. *Spore* provides a menu of architectural elements to tinker with: windows, doors, that kind of thing. The player clicks and drags the pieces onto a base structure and can stretch or shrink them along several axes. From the game's perspective, each building's design is simply a list of instructions; when the player is finished tinkering, those instructions direct the game engine to generate an image of the building and place it within the *Spore* world. Simple enough.

Then there's the process of making a creature, which offers a whole other level of variety and complexity. For instance, each creature can have any number of features and appendages—eyes, mouths, legs, feet—which can be stretched and curled like clay into outlandish shapes. But that indeterminacy presents an unusual problem: how exactly does a game company write software that generates realistic movements for "an eight-legged, two-headed thing with four mouths and no neck?" Wright says. "We don't know what we're animating."

To convincingly evoke even the wackiest animal a player could design, the game code had to be able to apply the knowledge of a human animator, on the fly—the ability to understand body language and subtle facial expressions and then to encapsulate those qualities



SIM EVERYTHING: Through the course of the game, creatures evolve from single-celled organisms into inhabitants of hyperadvanced societies. IMAGES: ELECTRONIC ARTS

abstractly in software. Wright decided to build *Spore*'s real-time animation around a technique called procedural generation. The "procedure" in *Spore* is a set of algorithms that execute a player's designs, generating entirely new content in the midst of game play. Other game developers have used the technique for years in a limited way, but no game has ever relied on it so heavily to create highly customizable yet lifelike creatures in real time.

So the Maxis team had little to go on as they tried to figure out how to make their exotic beasts move. Wright, who builds BattleBots for fun and possesses a voracious intellect and curiosity, decided to hit the books. He began reading up on biomechanics—in particular, the physics and physiology of how animals move. "Depending on the leg length and how supple the spine is," he says, "you can get a characteristic oscillation of the [torso] of the creature over the ground."

To get a creature to walk or run convincingly, the software engineers encoded an overarching set of rules on how to generate movement. The animation algorithms start by looking at the number of legs, the length of each leg, and the creature's bodily symmetry to calculate something called a walking ratio. If one side has twice as many legs as the other, for example, the ratio would be one to two. The algorithms will also compute the rhythm of a creature's footfalls—the length of time between, say, a front leg and a back leg hitting the ground in a single stride. The overall gait takes all these factors into account, along with the dimensions of the torso and head (or heads, as the case may be). The result is a convincingly lifelike motion.

The Maxis team then had to see if those movement rules worked on actual *Spore* beings. The team devised a huge menagerie of test creatures, observed how they stumbled around, and then adjusted the software's algorithms, essentially creating a virtual island of Dr. Moreau. "We have these tests where we take 10 totally crazy, random creatures and run animation on them," Wright says. "And we find out that it works for these seven, but for these two the legs look weird and for this one the back isn't straight enough. We're refining those algorithms all the time."

TO ILLUSTRATE, Wright goes over to his Dell computer and, with a few pecks at the keyboard, brings up the game's Creature Creator on screen. He starts with a short, fat torso and attaches birdlike wings on its sides for ears. From a palette of eyeballs, he clicks and drags a pair of big round eyes and drops them onto the beast's shoulders. He continues to tweak the anatomy, equipping the creature with legs, arms, hands, and so on.

Even as Wright experiments with different looks, the beast begins to move—wiggling its newly attached limbs and blinking its new eyes. It even seems to show its approval of certain choices by smiling and nodding.

Based on each new creature's features and shape, the animation software determines the sounds it can make, the way it dances, and much more. A skinny beast with a beak and decorative tufts of hair may flutter its eyelashes and emit a high-pitched warble, while a hulking creature with spikes along its spine may blink slowly and communicate in a baritone growl. Those traits in turn end up influencing whether the creature greets other species with a friendly advance or with an attack, and the fate of its civilization depends on those nuances.

Wright clicks on a button to test the creature he's just designed. With short legs on one side and long legs on the other, the animal lumbers awkwardly but convincingly across the screen. Indeed, the little legs scurry just fast enough to keep up with the long ones. But Wright isn't done with him yet. "What would it take to make any creature sad?" he asks, tapping away at the keyboard. Suddenly this alien being adopts a recognizably sad pose, dropping its torso, curling down the edges of its mouth, and dully drooping its eyelids. You feel kind of sorry for the little guy.

This beast is relatively straightforward, but the Maxis team had to allow for the most twisted possibilities a player might dream up—for instance, a creature with no limbs. "Now the game has to deal with all the ramifications of that," says Hecker. "So how do you pick up a piece of fruit?"

In conventional animation systems, the concept of a limb may be encoded not as an object but rather as a set of spatial transformations that can be applied to a body. To accomplish this, an animator can assign labels to parts of a character's skeleton. When a character reaches for that fruit, the animation might state something like, "Rotate bone 1 from 0 to 52 degrees."

But in *Spore* the skeleton is unknown until the game is already in play. So instead of using labels, the programmers encode generic descriptions of each body part, referring to a specific limb by describing its context relative to other body parts. Let's say a creature throws a punch at a bad guy. The animation may dictate the action with instructions that would read something like, "Move upper leftmost grasper from rest position to a position parallel to your leftmost head,

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

then move to some position relative to the enemy's topmost nose." The code analyzes the body in search of the parts that match that profile. In short, rather than directing bones to assume prescribed positions, animators are using higher-level directives to describe what the bones should do. This strategy was key to opening up a much wider field of character types and activities—though it certainly didn't make writing the game easy. The code can look for a limb by using a description that may be satisfied by one body part, several, or none. Coping with indeterminate results, while keeping the animation interesting by not simply ignoring extra limbs, drives up the complexity of the game code.

And then there are the creatures that are so weird they defy the game's generalized rules of movement. To catch those freakish cases, the code checks for certain features: for example, does the creature have any kind of paw or claw? If not, a separate set of instructions will govern the creature's movement, instructing it to use its mouth as a hand. And because the creature has no legs to use in calculating movement, it gets an inchwormlike slither. Rather than try to write very complex algorithms that cover every imaginable kind of beast, the programmers instead identified a few exceptional creature skeletons and wrote code that chooses different sets of rules for them. "It just kind of ripples out in a lot of different ways," Hecker says.

IT'S ONE THING to create and animate a creature in *Spore*, but Wright and his team knew that players would also want to share their creations. "What we saw with *The Sims* was that people loved downloading tools and creating stuff in the game," says Wright. Players routinely surfed Web sites specially set up for trading *Sims* add-ons, such as modifications to a character's appearance, houses, and furniture. But the experience was a hassle because players had to find and then import each item into the game one by one. "We wanted to basically make that [process] part of the game play," he says.

To do that, Maxis devised the Pollinator. This tool lets players easily search through the buildings, vehicles, and beasts created by other gamers and incorporate them into their own worlds. They can also sort through the stuff by theme—whimsical or *Wizard of Oz*, futuristic or "Futurama." This is what Wright means when he describes the game as "a massively single-player experience": it's a one-person game that can draw on many sources. While the *Spore* DVD will ship with some ready-made creatures and buildings—so that a player's creatures aren't initially running around in an empty universe—the rest of the content will come from the players, who can upload their creations to Maxis's game servers for others to access.

COMPOSING CREATURES: An editing palette gives *Spore* players free rein to create unique and curiously realistic characters.

To store and sift through such a huge amount of data, the Maxis team had to compress the data files down to a manageable size. Here, the hurdle became "how do we keep the data rate really low so that even if I'm not on the Internet I can still have the local database with lots and lots of content?" Wright says.

With its detailed terrains and texture maps, one planet in *Spore* could occupy 10 megabytes of space on a player's hard drive. "We don't have the disc space to deliver a million planets," says Maxis art director Ocean Quigley. When a player creates a planet, an instruction list for generating that world is saved along with certain seed values, which are like keys that the software uses to reopen the world later. To conjure up lots of different planets for each game, the code requires that certain values or quantities be more or less randomly assigned. Algorithms embedded in the game's software can generate those strings of seemingly unrelated numbers, but the starting value—or seed—must vary so as to avoid generating the same string of numbers each time the algorithms are run. "We want the planets to be 'random,' but we also need to be able to re-create it exactly when you come back later," Andrews explains. "Storing the seed lets us do that."

The programmers also had to winnow down the list to just the core guidelines needed to reconstitute a planet—or building, creature, or spaceship. Sometimes that meant making tough choices that in effect curtail a player's creativity. Originally, for instance, *Spore*'s Creature Creator allowed players to design animals with looped spines. Unfortunately, doughnut-shaped animals raised all sorts of exceptions to the animation rules. The solution: bye-bye, doughnuts.

To manage the flow of so many player-created creatures and items, and to help players find content they like, *Spore* uses the same kind of collaborative filtering that sites like Amazon and Netflix have made popular, based on the preferences of other players who have chosen a certain design. Players will also be able to subscribe to Sporecasts—a kind of RSS feed of content other people create for the game. As *Spore* spreads, stars of content design will likely emerge, as they have in *Second Life* and in other online gaming communities.

"I can imagine so many cool possibilities that we're just scratching the surface of," Wright says. He envisions *Spore* races centered around user-designed vehicles and flying games featuring users' spaceships.

But Wright's imagination stretches only so far. He anticipates the day when *Spore* players take charge and steer the game into unseen territory. "That's when the fans become an even larger designer [than us]," he says. "In some sense, we're kind of codesigning *Spore*. Fans are going to drive its future." ❑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BEYOND SILICON'S ELEMENTAL LOGIC

IN THE QUEST FOR SPEED, KEY PARTS OF MICRO-PROCESSORS MAY SOON BE MADE OF GALLIUM ARSENIDE OR OTHER III-V SEMICONDUCTORS BY PEIDE D. YE

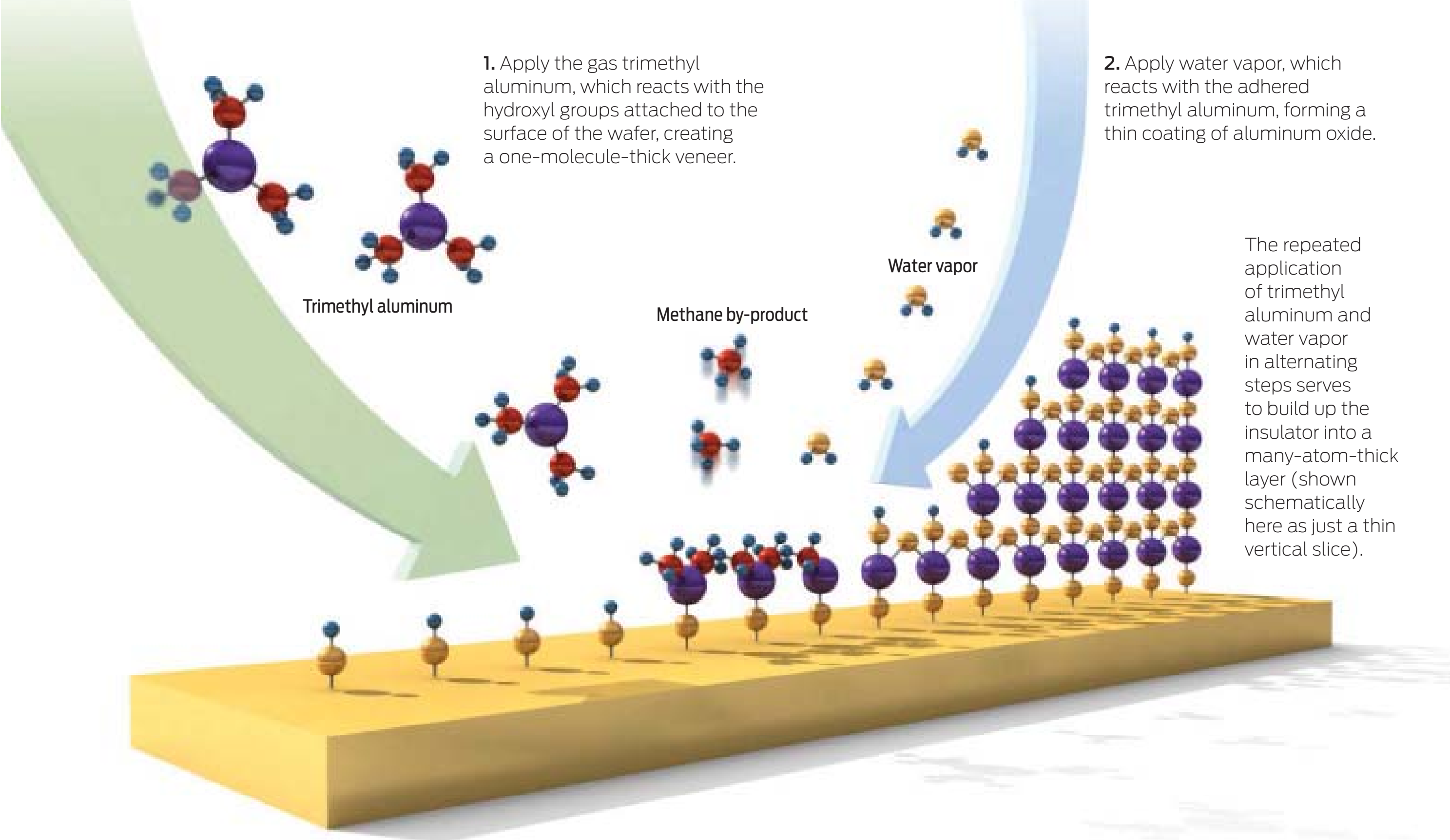
THE FIRST general-purpose microprocessor, the Intel 8080, released in 1974, could execute about half a million instructions per second. At the time, that seemed pretty zippy.

Today the 8080's most advanced descendant operates 100 000 times as fast. This phenomenal progress is a direct result of the semiconductor industry's ability to reduce the size of a microprocessor's fundamental building blocks—its many metal-oxide-semiconductor field-effect transistors (MOSFETs), which act as tiny switches. Through the magic of photolithography, billions of them are routinely constructed en masse on the surface of a silicon wafer.

As these transistors got smaller over the years, more could fit on a chip without raising its overall cost. They also gained the ability to turn on and off at increasingly rapid rates, allowing microprocessors to hum along at ever-higher speeds.

But shrinking MOSFETs much beyond their current size—a few tens of nanometers—will be a herculean challenge. Indeed, at some point in the next several years, it may become impossible to make them more minuscule, for reasons

ALL ARTWORK: BRYAN CHRISTIE DESIGN



ATOMIC-LAYER DEPOSITION provides one means for coating a semiconductor wafer with a high-*k* aluminum oxide insulator. The benefit of this technique is that it offers atomic-scale control of the coating thickness without requiring elaborate equipment.

of fundamental physics rather than nuts-and-bolts engineering. So people like me have been looking at other ways to boost their speed. In particular, we've been laboring to build them using compound semiconductors like gallium arsenide, which would allow such transistors to switch on and off much faster than their silicon cousins can.

This strategy is by no means new. Practically ever since the silicon MOSFET was invented in 1960, engineers have been attempting to come up with a gallium arsenide version suitable for large-scale integrated circuits. No one has yet succeeded. Those repeated failures have led to the oldest joke in Silicon Valley: gallium arsenide—it's the technology of the future, and it always will be.

But that perennial skepticism may be about to vanish. My colleagues and I at Purdue University's Birck Nanotechnology Center, in West Lafayette, Ind., along with other researchers in industry and academia, have recently made some advances that might soon allow transistors built with gallium arsenide or a related compound to be used for large-scale digital ICs. That capability would go a long way toward bringing us microprocessors that can blaze along at triple or even quadruple the speed of today's best. Achieving that goal will no doubt require other improvements in semiconductor technology to take place in parallel, but gallium arsenide or something close to it could be key. No wonder some of us have been unwilling to give up on this remarkable material.

GALLIUM ARSENIDE'S two main components come from the third (gallium) and fifth (arsenic) columns in the right-hand portion of the periodic table of elements, which is why cognoscenti refer to it as a III-V semiconductor. There are more than a dozen such compounds, including gallium nitride and indium phosphide, but gallium arsenide is the most common example and therefore the best studied. It currently accounts for about 2 percent of the semiconductor market.

Gallium arsenide devices cost a lot more than ones built of silicon—the raw materials are about 10 times as expensive—but they serve well for certain specialized applications, including high-efficiency solar cells, laser diodes, and one very special kind of field-effect transistor: the high-electron-mobility transistor, or HEMT, which is used in cellphones, communication systems, and radars, among other things.

HEMTs are remarkable devices because they overcome a fundamental problem of solid-state physics. Semiconductors, as their name implies, normally don't conduct electricity all that well.

Usually, they must be doped with other kinds of atoms to become electrically conductive. But those impurities tend to interfere with the movement of electrons through the semiconductor's crystal lattice, limiting the conductivity that can be obtained.

In HEMTs, electrons are introduced into a III-V semiconductor not by doping but by placing the material in contact with another III-V compound that *is* doped. In essence, electrons fall a short distance into the undoped material, allowing a thin layer of it—the channel—to conduct electricity extremely well whenever the transistor is switched on.

HEMTs can be used singly or in integrated circuits with, say, 100 or even 1000 of them clustered together, but they can't yet work for microprocessors. The problem is that too many of the electrons that are supposed to flow through the channel from the transistor's source electrode to its drain instead seep out the controlling input electrode—the gate—creating heat. With millions of leaky transistors crowded together on the same chip, things would quickly get hot enough to melt.

In a silicon MOSFET, a layer of intervening insulation (traditionally silicon dioxide) prevents electrons from slipping out of the channel into the gate. In a HEMT, the channel is separated from the gate by a semiconductor, which, as you might expect, is somewhat conductive. What's needed here, of course, is an insulator, but for decades there have been no good gate insulators available for gallium arsenide. From time to time over the years, researchers seem to uncover a promising material, but nothing ever really panned out—until recently.

It's easy enough to understand, at least in general terms, why finding a gate insulator for silicon was easier than it has been for gallium arsenide. Silicon dioxide is a native oxide of silicon—a naturally forming coat that grows when silicon is exposed to oxygen. By good fortune, silicon dioxide makes for an excellent chemical marriage with the silicon it covers: only one out of 100 000 silicon atoms at the interface fails to bond with the adjacent silicon dioxide, leaving what's called a dangling bond. These defects disrupt the flow of electrons in the channel, but they are rare enough that they don't materially degrade the performance of a transistor.

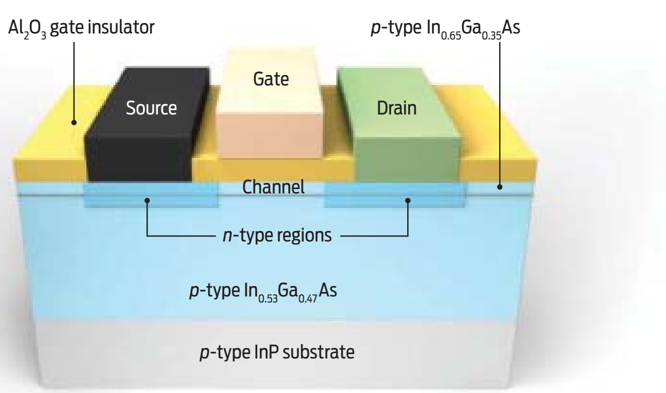
Gallium arsenide is a different story. When it oxidizes, it forms a complex mixture of Ga_2O_3, As_2O_3, and As_2O_5. Beginning in the 1960s, some researchers tried using these native oxides for a gate insulator, but that tactic proved worse than useless because the native oxides create all kinds of defects at the interface with the gallium arsenide, which destroy the electrical conductivity of the adjacent channel. Clearly, a better material needed to be found if there was to be any hope of making gallium arsenide MOSFETs for digital ICs.

RESEARCHERS continued the decades-long quest, testing silicon dioxide, silicon nitride, silicon oxynitride, and aluminum oxide, among other candidates. They also tried adding a third material, such as sulfur, silicon, or germanium, between the substrate and the insulator to negate the pernicious effects of dangling bonds. Yet the results always proved disappointing, and by the early 1990s most investigators had simply given up. Two notable exceptions were Minghwei Hong and Matthias Passlack at Bell Labs, who had developed a way of depositing a combination gallium oxide–gadolinium oxide insulator on a III-V substrate, a strategy that Passlack later refined at Motorola and at a company Motorola spun off in 2004, Freescale Semiconductor.

At that time, the engineers making silicon MOSFETs were beginning to experience trouble with their gate insulator too. As the dimensions of these transistors shrank, the silicon dioxide insulating the gate no longer functioned well. Indeed, it became so thin that electrons could pass through it as if it were a sieve. Great effort went into finding alternative materials with higher dielectric constants, which could be made physically thicker without compromising the electrical functioning of the transistor. Eventually, suitable compounds were found. Intel, for instance, is now using a hafnium-based gate insulator on some of its most advanced microprocessors [see "The High-*k* Solution," *IEEE Spectrum*, October 2007].

To control the thickness of these "high-*k*" dielectrics (a designation that refers to the symbol used for a material's dielectric constant, the Greek letter kappa), manufacturers apply them to the silicon substrate using a technique called atomic-layer deposition. It's quite ingenious, really. The trick is that you employ a chemical carrier molecule that sticks to the target surface but not to itself. Such a chemical thus deposits a one-molecule-thick veneer. A second treatment with another carrier molecule removes the first carrier, leaving a two-atom-thick layer of the desired material behind. Repeated application of the two carrier gases, one alternating with the other, allows chip makers to deposit various high-*k* gate insulators on silicon with atomic-level precision.

In 2001, Glen Wilk, then my colleague at Bell Labs, and I decided to try to put a high-*k* gate insulator—in this case, aluminum oxide (Al_2O_3)—on top of gallium arsenide using atomic-layer deposition, which was all the rage at the



AN EXPERIMENTAL TRANSISTOR of indium gallium arsenide (blue) is built on a bed of indium phosphide (gray). Positive voltage applied to the gate draws electrons into the channel between the silicon-doped *n*-type regions beneath the source and drain electrodes, allowing current to flow.

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

YEARS IN THE MAKING

1960 Dawon Kahng and Martin M. Atalla at Bell Labs invent the MOSFET.

1965 Hans Becke, Robert Hall, and Joseph White at RCA devise the first gallium arsenide MOSFET using silicon dioxide for the gate insulator.

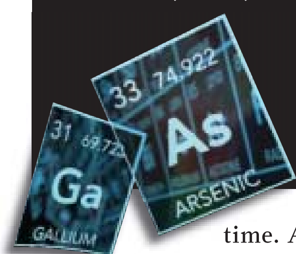
1979 Takashi Mimura at Fujitsu Laboratories invents a type of gallium arsenide FET: the high-electron-mobility transistor (HEMT).

1995 Minghwei Hong and Matthias Passlack at Bell Labs deposit a gallium oxide–gadolinium oxide insulator on a III-V substrate.

2001 The author of this article, Peide Ye, and Glen Wilk deposit an aluminum oxide insulator on a gallium arsenide substrate using atomic-layer deposition.

2005 Intel announces interest in III-V semiconductors for future microprocessors.

2007 The author and his colleagues measure record-breaking current for a III-V MOSFET.



time. After 2003, our team continued to study this approach at Agere Systems, in Allentown, Pa., a spin-off of Bell Labs and Lucent Technologies, where our group had been moved. The maneuver succeeded better than we could have dreamed.

That's not to say we were able to make a perfectly functioning MOSFET out of gallium arsenide straight off. Rather, what stunned us early on was that atomic-layer deposition allowed us to apply the Al_2O_3 despite having done nothing to remove the troublesome native oxide from the gallium arsenide. The reason, as researchers at the University of Texas at Dallas have recently detailed, was that the first carrier, a molecule called trimethyl aluminum, eats away at gallium arsenide's native oxides, which despite all reasonable precautions tend to cover the substrate. It's the atomic-scale equivalent of the mold on an old porch floor. And as any homeowner knows, if you want to repaint those boards, you'd better scrape off the gunk first.

Using trimethyl aluminum was like having an all-in-one product that strips, primes, and paints all at once. If you want additional coats—that is, a thicker film of Al_2O_3—just repeat the application of trimethyl aluminum and the second carrier, water vapor, in alternating steps.

Once you grow a suitably thick layer of aluminum oxide on gallium arsenide in this way, you use traditional lithography to construct the drain, source, gate, and other components of a MOSFET. No special processes are required. The rub is that the transistor you'll end up with will be a dud: it won't pass any more current through its channel than did some of the failed designs of decades past.

When I came to Purdue three and a half years ago, Yi Xuan, a postdoctoral investigator in my research group, and I took on this problem of dismally poor current capacity. At about that time, Intel announced that its engineers were seriously considering the use of III-V semiconductors in its future chips. IBM, too, made its interest in this technology known. The quest for speed, it seemed, was driving a renaissance in research on how to make III-V semiconductors for digital applications. But despite all this attention from some of the biggest guns in the industry, nobody had a clear idea about how to achieve sufficient current-carrying capacity for III-V MOSFETs. The challenge was greatest for those operated in enhancement mode, meaning that electrons flow from source to drain only when a voltage is applied to the gate, as is the case for the silicon MOSFETs found in digital ICs.

Based on published work carried out almost a decade earlier at Bell Labs and on my own research on depletion-mode MOSFETs, which switch off when voltage is applied to the gate, I realized that a related III-V semiconductor—indium gallium arsenide—would serve better for the channel. In this compound, indium atoms substitute for galliums to a degree that can be adjusted arbitrarily. That is, you can have mostly indium atoms, mostly gallium atoms, or a 50:50 mix of the two bonding to the arsenic atoms.

Tinkering with the indium content allowed us to engineer the substrate's electronic properties as required, instead of trying to work around the givens of a particular material. After much experimentation, we settled on a composition that had a 65:35 ratio of indium to gallium. With it we were able to build a MOSFET that carried more than 1 ampere per millimeter of channel width—the highest current density ever produced in four decades of work on gallium arsenide MOSFETs. Indeed, it was so large that it initially sent our semiconductor parameter analyzer off scale!

One well-known difficulty with this approach is that indium gallium arsenide has very poor mechanical properties, so poor that it would be problematic, if not impossible, to use it to make wafers. Pure gallium arsenide is much more robust. Our wafer supplier, a UK-based company called IQE, was able to overcome this hurdle by growing a thin layer of indium gallium arsenide on a thick base of indium phosphide. These two compounds have crystal lattices of similar sizes, so they bond reasonably well together. And the mechanical properties of indium phosphide, while not ideal, proved good enough to allow us to construct various test transistors.

Passlack and his colleagues at Freescale Semiconductor and the University of Glasgow have also been experimenting with indium gallium arsenide over the past few years, using a gallium oxide–gadolinium oxide insulator. Hong, who is now at National TsingHwa University in Taiwan, continues work on this combination as well. Although such MOSFETs have shown a reasonably good ability to carry current, they would be difficult to manufacture. The problem is that they require two applications of a high-vacuum deposition technique called molecular-beam epitaxy: one to lay down the indium gallium arsenide and then a second to coat it with the gate oxide. Doing molecular-beam epitaxy twice, all the while keeping things under high vacuum, is possible in the lab, but it would be a challenge for industrial-scale production.

Research groups at the National University of Singapore and at IBM are pursuing yet another design that has lately shown promise, one that uses chemical means to add a layer of amorphous silicon between the semiconductor and the gate insulator. This approach resembles a strategy that was attempted two decades ago and is similar to work going on now at the University of Texas at Austin and at the State University of New York in Albany.

What's more, some researchers are looking to build a very different kind of III-V field-effect transistor suitable for digital applications, one that can function without a gate oxide at all. These devices operate similarly to HEMTs in that a semiconductor provides the barrier between the gate and a highly conductive, undoped channel. Intel and UK-based QinetiQ in particular have over the past few years achieved impressive performance with a transistor fashioned this way using an indium antimony channel. Jesús A. del Alamo and his colleagues at MIT are also investigating how to make such HEMT-like transistors smaller and less prone to gate leakage so that they may one day serve for digital applications.

Indeed, much work goes on around the world on bringing III-V semiconductors into what has long been the sole domain of silicon. In addition to the efforts being mounted in industry, academic teams have formed centers of research at the University of California at Santa Barbara, the University of Glasgow, and the University of Tokyo, specifically to carry out these investigations.

CONSIDERABLE progress will yet have to be made before any of these new kinds of field-effect transistors replace their slower silicon counterparts in microprocessors, memory chips, and other digital ICs. In particular, device engineers will have to optimize many parameters besides current-carrying capacity and gate leakage. They'll also want these transistors to be able to operate at low voltages, for instance, so as to reduce another troublesome source of heating: the power expended at the moment the transistors switch states. (Indium-rich indium gallium arsenide holds great promise in this regard.) Designers will also want to ensure that very little current flows when a transistor is nominally "off," so that power isn't expended—and heat isn't generated—uselessly. Doing so, all while making these transistors as tiny as today's silicon wonders, will be no small feat.

In addition, it is likely that manufacturers will have to find ways to place III-V semiconductors on top of a silicon wafer. That is, chip makers will surely aim to use the compound semiconductors only where they're needed rather than trying to replace silicon entirely, although getting all these materials to work properly together turns out to be a tricky undertaking and the subject of much research.

One reason for keeping as much silicon as possible around is that it has considerably better physical properties for making the large wafers used in semiconductor manufacturing. Also, silicon is cheap and environmentally friendly, whereas gallium arsenide is expensive and, because it contains arsenic, potentially quite toxic.

Another reason not to expect an all–gallium arsenide microprocessor anytime soon is that III-V semiconductors can speed up only half the transistors in a CMOS chip: the *n*-channel ones, which carry current in the form of negative charges—electrons. CMOS integrated circuits require a combination of both *n*-channel and *p*-channel MOSFETs, which together draw power only when they switch states, such as when an *n*-channel transistor turns on and the *p*-channel transistor that's wired in series with it turns off. When not switching between states, such a complementary pair draws no power, which is what makes CMOS chips so energy efficient.

Although gallium arsenide allows electrons to move through it especially easily, it doesn't offer any advantage over silicon for positive charge carriers—the "holes," which are sites in the semiconductor's crystal lattice that are deficient in outer-shell electrons. So it would be very difficult to make a high-performance *p*-channel MOSFET using gallium arsenide or another III-V compound. The current consensus is that the semiconductor industry will probably employ germanium for those transistors. The Duallogic academia-industry consortium in Europe, for example, is working to combine germanium and III-V semiconductors in this way.

The III-V devices that my Purdue colleagues and I have recently constructed represent a whopping leap forward, as these MOSFETs are both easy to fabricate and able to carry record currents. The competing designs offer some attractive features too. Still, many barriers stand in the way of their widespread use. In particular, chip makers will have to learn to mix and match some very different kinds of semiconductors on a single wafer. Perhaps chip makers will have to weave together a patchwork quilt of indium gallium arsenide and germanium on a bed of silicon, or maybe it will be something even more complicated. But if there's any lesson to be drawn from the past four decades of dizzying advances in computing power, it's that this industry thrives on a challenge. ❑

TO PROBE FURTHER Details of the author's work in this area are available in "High-Performance Inversion-Type Enhancement-Mode InGaAs MOSFET With Maximum Drain Current Exceeding 1 A/mm," by Y. Xuan, Y.Q. Wu, and P.D. Ye, IEEE Electron Device Letters *29:294, April 2008.*

To learn more about the use of a gallium oxide–gadolinium oxide insulator on a III-V substrate, see "High Mobility III-V MOSFET Technology" by M. Passlack, R. Droopad, K. Rajagopalan, J. Abrokwah, P. Zurcher, R. Hill, D. Moran, X. Li, H. Zhou, D. Macintyre, S. Thoms, and I. Thayne at http://www.gaasmantech.org/Digests/2007/2007%20Papers/12c.pdf.

JON RUBINSTEIN ORCHESTRATED A LITTLE MUSIC

FROM PODFATHER

PLAYER FOR STEVE JOBS THAT TURNED APPLE AROUND.

TO PALM'S PILOT

CAN HE REPEAT THAT MAGIC AT PALM? BY TEKLA S. PERRY

FLASH BACK TEN YEARS. Apple is a company bleeding money, thought by many to be in a death spiral. Its head of hardware development, a 41-year-old electrical engineer named Jon Rubinstein, is busy cutting projects and people and launching the G3 and iMac computers. He's living in Palo Alto, Calif., with a cat for companionship, working seven days a week, and subsisting on take-out food at the office.

Then came the iPod.

In 2001, on a business trip to Japan, Rubinstein visited Toshiba, where his hosts trotted out a 1.8-inch hard drive they were working on. They thought it was interesting but weren't really sure what they could do with it. Perhaps Jon had some ideas?

You know those hokey cartoons where the lightbulb goes off over somebody's head, indicating a brilliant idea? That was Jon, sitting there in that Toshiba office. "I'm, like, 'Yeah, I know exactly what to do with *that*,' " he recalls.

Some four months before, Steve Jobs, his boss, told him to check out the possibility of designing an Apple music player. "He told me to see what it would take to do it and see if I think we can do it," Rubinstein recalls. "My first reaction was 'Hey, we're really busy right now. I don't need more on my plate.' " But, of course, that's not the sort of thing you say to Steve Jobs. So what Rubinstein actually said was, "Okay, I'll go take a look at it." He did the research and decided that a music player just didn't make sense for Apple at the time, because the device would have to be too big and clunky to be appealing or it simply wouldn't hold enough songs to be useful. He shelved the idea indefinitely.

Then he saw the Toshiba hard drive. The lightbulb went on. And the rest is consumer electronics history.

Suddenly, he was running a crash project to develop a little music player that became

MARK RICHARDS

the iPod, which revolutionized the music industry, pushed Apple into the Fortune 200, launched a thousand business-school case histories, and will be described in books (or whatever succeeds them) a century from now.

THESE DAYS, RUBINSTEIN lives in a San Francisco high-rise with his wife of six years and two dogs. (The cat died.) He takes the train to Sunnyvale, where, as executive chairman of the struggling smart-phone maker Palm, he's tackling another turnaround. If all goes well, he'll soon be competing more or less head-to-head with his former mentor—Jobs.

But not everything has changed. Rubinstein still pads around the house barefoot, buys his jeans at budget retailer Mervyns, and gripes about the cost of running shoes. His income, place of residence, and age suggest he should be driving a Porsche Carrera or maybe a Mercedes SL 550. But he doesn't even own a car. "I do drink better wine these days," he says.

At Palm, Rubinstein is essentially expected to do what Steve Jobs did for Apple. That is, take a once-high-flying company heading for oblivion and, through product innovations, make it a player again. Palm helped create the smart-phone market with the Treo, then lost ground to the BlackBerry and, more recently, the iPhone. Rubinstein's job is to get Palm back into the race. "Palm can be saved," says Ken Dulaney, an analyst at Gartner's San Jose, Calif., office. "They had a great product, though they stuck with it too long. Their name is known."

But, says Dulaney, the next product is critical: "If they don't come up with a good piece of hardware next, they'll be crippled." The rumor mill says that product will be a Web-surfing phone that will blow the iPhone out of the water and that it'll be coming in the first half of 2009.

RUBINSTEIN SAYS he's always been "a product guy." It's just that the hardware keeps getting smaller. First, in the early 1980s, after he graduated with a master's in engineering from Cornell, he worked on test methods for computer production at Hewlett-Packard. Then he helped design subsystems for the HP 9836 workstation. In 1986, start-up Ardent Computer, headed by industry legend Gordon Bell, hired Rubinstein to help design a new kind of compact, graphics-oriented supercomputer.

Then, in 1990, Steve Jobs came calling. He wanted Rubinstein to help develop reduced-instruction-set computing workstations at NeXT Computer, the quirky but influential start-up Jobs launched during his years of exile from Apple. Alas, NeXT ran out of money before it could ship anything Rubinstein worked on.

With Jobs's blessing, Rubinstein took some of the technology he had been developing and started a company called Firepower Systems to build PowerPC-based personal computers. However, when IBM killed its own PowerPC line and stopped investing in the market, Firepower's business was pretty much destroyed. Still, he made a tidy profit six months later when he sold Firepower to Motorola. Weary of the high-tech merry-go-round, at age 40 he began what he intended to be an extended vacation.

But in January 1997 Jobs called again. He was selling NeXT to Apple and wanted Rubinstein as senior vice president of hardware engineering. How could he say no to the great persuader? Apple was at a low point, with annual sales of US $9.8 billion, down from more than $11 billion the previous year. Its Power Macintosh computers were running tired six-year-old System 7, and it had only 3 percent of the personal computer market, down from over 9 percent in 1993.

Rubinstein and the rest of Jobs's executive team revamped the company's culture, product line, and engineering teams. By mid-1999 the company's computer business was becoming healthy again, although its market share, still hovering around 3 percent, was hardly more than a footnote in the PC marketplace.

AND THEN CAME ITUNES. In late 2000, Apple was caught short when Hewlett-Packard introduced computers with built-in CD burners. Apple needed to add burners to its line quickly and also develop software to support them. It bought the rights to an MP3 player called SoundJam and brought one of its developers, Jeff Robbin, who had worked for Apple in the 1990s, back to the company to work on the project that would be iTunes. The main thing he needed to add was the ability to seamlessly burn CDs from within the program.

That first generation of iTunes mostly stored music in a library and burned CDs from that library. But it also had to support at least some of the digital music players then on the market. So as part of the iTunes project, Apple engineers bought various digital music players, including Creative's Nomad, Diamond Multimedia's Rio, and Philips's Nike.

"They were horrible," Rubinstein recalls. "The small solid-state ones could hold, like, six songs. The hard-drive ones were really big and ugly and took all day long to download music. It was just an awful experience.

"We started kicking around the idea of doing our own music player. Steve told me, 'Look into it.' We all wanted one that was better than what was out there, but we were really busy."

Rubinstein formed a small team to investigate. They looked at technologies and tossed around ideas, but they just couldn't identify a "home run product," as Rubinstein puts it.

"I kept telling Steve that it wasn't time yet," he recalls. Jobs trusted Rubinstein's instincts and, uncharacteristically, didn't push too hard.

In February of 2001 Rubinstein went to Japan on an annual trip to visit hardware suppliers and look at technologies under development. It was a whirlwind—about four days and seven companies. It was at the end of his otherwise routine meeting with Toshiba executives that they showed him the tiny disk drive. Rubinstein's mind was churning, even as he tried not to let his expression change. He immediately recognized the minuscule marvel as the missing piece of the music-player puzzle. Almost all of the other disk drives available then were a comparatively clunky 2.5 inches in diameter. The 1.8-inch drive offered up to 5 gigabytes,

JON RUBINSTEIN

IEEE SENIOR MEMBER

TITLE: Executive Chairman, Palm Inc.

DATE OF BIRTH: 13 October 1956

EDUCATION: BSEE 1978, M.Eng. 1979, Cornell University; MSCS 1985, Colorado State University

FAMILY: Married to Karen Richardson

COMPUTER: Black MacBook

CAR: None; relies on public transportation or rents a Zipcar

MOST RECENT BOOK READ: *The Path Between the Seas: The Creation of the Panama Canal 1870–1914* by David McCullough

FAVORITE RESTAURANTS: Masa's, Aqua, and Yank Sing, all in San Francisco

LEISURE ACTIVITIES: Distance running, biking, scuba diving, skiing compared with 25 for the larger units, but 5 GB was enough to hold about 1000 songs in the MP3 format. And the diminutive drive sucked down roughly half the power of the 2.5-inch drives then standard in notebook computers: when active, the drive drew 1.3 watts compared with the 2.3 of its 2.5-inch brethren; while asleep, it needed only 0.05 W compared with the 0.10 of a typical 2.5-inch drive. With some smart engineering, that lower consumption meant approximately 10 hours of playing time.

"It clicked right away," Rubinstein recalls. "I had visited lithium-ion battery manufacturers. I instantly knew exactly what battery we'd need to use. I'd been to display vendors, and the capability, size, and costs of displays that were coming would make this extremely feasible." The prices of small LCDs had plunged, thanks to the demands of the cellphone industry.

But "the key element was the drive," he insists. "Before that, we had two choices—do a big clunky device or do a device that held a dozen songs. Neither made sense. But once I saw the 1.8-inch drive I said, 'Okay, now I know how to do it.' "

Talk about good timing. Had Rubinstein made that routine trip to Japanese suppliers a month earlier, the drive might not have been ready to show; a little later, and a competitor might have seen it first.

Jobs, coincidentally, was in Tokyo for the Macworld conference, so Rubinstein didn't have to wait for morning in California to call him with the news. He met Jobs at the hotel and uttered eight words that would set in motion one of the great revolutions in consumer-product history. "I said, 'Hey, I know how to do this now.' He goes, 'Great, I'll write you a check.' That's what he always would say when we kicked off a project." It meant that Rubinstein now had authorization to pull together a development team and start them working full-out on the project.

The full-time development team was small, between six and eight people during much of the project. Rubinstein brought on Tony Fadell as a consultant to help figure out the details; he later hired Fadell to run the group. Jonathan Ive, Apple's senior vice president of industrial design, made prototype after prototype. Phil Schiller, then Apple's head of product marketing, jumped onto the idea of the scroll wheel; he had the insight that it should scroll more quickly the longer it's turned, an innovation that has been endlessly imitated. Jeff Robbin led a team that worked closely with Jobs on the iconic software interface.

Along the way, more than 100 engineers within Apple worked on the project, hundreds more at the companies that would supply subsystems. And of course, iTunes and the online music store developed in parallel with the iPod share credit for the device's success.

THE IPOD PROJECT got under way officially in March 2001, with Jobs demanding a product out for Christmas. That meant it would have to be in mass production by October—seven months away. So the tiny team acted more like hunter-gatherers than like farmers. They didn't start from scratch; they had to rely on existing projects within the company, adapting them to their goals. Apple's display group helped them choose screen technologies and build the display drivers and related components. The power supply group took the specs from the iPod team and designed the "wall wart," Rubinstein says, as well as the power-management circuitry that would go inside the device. And the mass storage team worked closely with Toshiba to finish the tiny hard drive, which had simply been a prototype when Rubinstein saw it. They debugged the design, tested it, and helped Toshiba shake out the production process.

Rubinstein told his Toshiba colleagues he'd buy every 1.8-inch drive the company could make. "They were a little surprised," Rubinstein recalls. And that was *all* he told them until Jobs officially introduced the iPod. "I told them not to worry; it was for a hot new product," he recalls. If at some point they figured it out on their own, they never let on to Rubinstein.

Convincing people throughout the company to take a little time for this top-secret skunk-works effort wasn't hard, Rubinstein notes, even though most people at the company weren't aware that the project existed. People were pulled over to iPod devel-

THE MAN IN THE PLAID FLANNEL SHIRT: Few people who see this casually dressed engineer realize that he managed the birth of the iPod.
PHOTO: MARK RICHARDS

opment as needed; "the hard part was focusing them back onto their normal jobs," he says.

Meanwhile, the Silicon Valley economy was slipping into free fall as the dot-com boom went bust. Apple stock fell from $55 a share in mid-2000 to around $12 a share in mid-2001. "We just kept our heads down," Rubinstein recalls. "We were busy. We thought when the economy turned around we'd be well positioned." Then, just as iPod production began in China, with kinks in the manufacturing process still being worked out, the 9/11 terrorist attacks rocked the world. The ensuing security measures trapped some of the key engineers on the project in China and left others stuck in the United States trying to get overseas to the factories.

Nevertheless, by October, just as Jobs had decreed, iPods were rolling off assembly lines. They worked well, except for one nasty bug. At roughly 10 hours of use, "battery life was good," Rubinstein says, "but a bug made it look like batteries were going bad." A software update a few months later fixed the problem.

From the moment he'd seen the 1.8-inch disk drive, Rubinstein hadn't had much doubt that the eventual product would be a runaway hit. But even he was unprepared for the visceral reaction it provoked—even in himself. "We all wanted one," he says, "and that's usually key. And everyone who used one loved it."

Okay, you may know some of that history. But what you probably don't know is that during the precise period the iPod design saga was playing out, a whole other drama was unfolding in Rubinstein's personal life. Just before the discussions about doing a little music player began in September 2000, Rubinstein met Karen Richardson, then CEO of E.piphany, a company launched by Rubinstein's close friend Steve Blank.

Blank knew what Rubinstein was looking for in a woman—"smart, tough, and pretty," he says, "maybe in that order," and Richardson had it. Blank was also pretty sure that Rubinstein was right for Richardson. People had been trying to introduce the two for years, but busy schedules got in the way. "It was like the Keystone Cops," Blank recalls. "My wife and I kept having these big events. We'd invite them both. First one made it, the other didn't. Then the other made it, and the first one didn't."

Finally, Blank got them both to his house for a small dinner party. Within 30 days they were an item.

So, in the midst of shepherding the iPod and running the rest of Apple's mechanical engineering, chip design, industrial design, and several other departments, Rubinstein was also helping to plan a wedding for 13 October 2001—10 days before the planned iPod launch, postponed a bit so that Rubinstein could get away for a one-week honeymoon to local beach retreats Big Sur and Stinson Beach. Rubinstein had to interrupt his honeymoon only once to go to the office to recut the audio track for the video to be shown at the launch.

The reaction at the introduction was mixed. People thought the new device was cool, Rubinstein says, but at $399, overpriced. "I told everyone, 'Look at what some people will pay for a pair of Nikes.' " It's an interesting comparison, in view of the fact that he himself looks for discounts on last year's sneakers.

Sales were solid but not spectacular. As it turned out, the obstacle wasn't price but PC compatibility. In intense debates within the company, Rubinstein supported opening up the iPod to Microsoft Windows. He based his argument on his experience with the AirPort Express wireless base station, which actually did support PCs but lacked a PC setup assistant and a dedicated marketing channel. As a result, AirPort didn't do nearly as well as it could have, had the company gone after the PC market. But the internal thinking was that the purpose of AirPort products was to sell more Macs. "We didn't understand that it would be a multibillion-dollar business, so we basically handed the business to Linksys."

Rubinstein didn't want Apple to repeat that mistake with the iPod. It didn't. Within six years of its introduction, Apple sold 100 million iPods. By comparison, DVDs sold 44 million units in the same initial time span.

Even as he took the helm of the newly created iPod division, Rubinstein began talking to Jobs about making a graceful exit from Apple. He gave Jobs 18 months' notice—time enough to bring out the next generation of iPods, the Video iPod and the Nano—and even get the iPhone team assembled and some of the core technologies in place.

The conventional wisdom on Rubinstein's departure was that he'd had a bitter falling-out with the notoriously mercurial Jobs. Not so, Rubinstein says. "I just wanted to take a break," he explains. "There was nothing negative about it. We announced [the resignation] to Wall Street six months before I left. I was not leaving because I was mad. I was just tired. I had worked with Steve for 16 years. He said that I deserved an award for that. We did some really great products together."

Jobs, says Rubinstein, drove him to do things he wouldn't have done on his own. "And I added the discipline and execution that it takes to continue getting products out the door," he says. "We did well together."

Rubinstein left Apple in the spring of 2006 a rich man; the profit from the stock options he exercised in 2004 alone was $26.3 million. He would never have to work again. But he knew he would.

He went to Mexico. Some years before, he had bought land in a coastal community on the Pacific. He planned to build a 1500-square-meter house on the property from a design by the Mexican architect López Baz y Calleja. Rubinstein decided to supervise the construction, which had already begun.

"Supervise" quickly came to mean "minutely engineer," especially for the house's extensive and state-of-the-art technical subsystems. He designed the home's computer networks, of course, along with its electrical system and backup systems that would compensate for Mexico's frequent outages. He designed a water system that stores drinking water from the city's irregular supply and filters it, along with a separate system that collects and stores rainwater for irrigation. He even helped design a compact waste-treatment plant for the house.

He approached the house as though it were a big iPod. He looked around, found the best components, and then designed custom systems to make them work together. For example, here was one problem: the heat pump that warmed the Jacuzzi was slow. Solution: integrate that system with the house's robust hot-water system, using heat exchangers and various controllers and timers to allow the recirculating water to pick up heat from the house system.

His pal Blank had just finished building a big house when construction on Rubinstein's began. Blank recalls giving Rubinstein a tour that included his pool house, a Rube Goldberg nightmare of crisscrossing pipes and labyrinthine connections—typical, he says, for pool plumbing. "I think he was rolling his eyes," Blank says, chuckling. He recently saw Rubinstein's pool water system and was stunned. "The plumbing looks like a circuit board layout," he marvels. "I don't know how he did it. There's not a single pipe that crosses another."

Rubinstein spent a year and a half working on the house, running, biking, kayaking, scuba diving, and just hanging around with his wife. He got regular calls inviting him to serve on corporate boards but turned every single one of them down. After the insanity at Apple, it was just too much fun doing nothing.

Then, in May of last year, he got a call from Elevation Partners principals Fred Anderson and Roger McNamee, along with Palm CEO Ed Colligan. Elevation was considering buying a 25 percent stake in Palm and taking on the challenge of transforming the company. They wanted to know if Rubinstein would be willing to come on board if the purchase went through.

Rubinstein had been a friend of Anderson and McNamee for years but had never met Colligan. So a few days later Colligan flew down to Mexico so the two could spend a few days getting to know each other. The fact that the struggling Palm, a once-innovative leader, was in a position similar to Apple's at the time Rubinstein joined appealed to him. And he saw a lot of potential in mobile devices; there would be multiple winners, and Palm could easily be one of them. "I liked the idea of another recovery project," he says. "I also love doing products and being in a space where the trend is your friend."

They weren't asking him to take on the full-time responsibility of running the company—Colligan would do that. Instead, Rubinstein would oversee major decisions and get involved in the nitty-gritty details as much or as little as he felt he should. He would set Palm's course. But he'd also have a little time for a personal life—in theory, anyway. Rubinstein took only a day or two to decide to go for it.

So now he's executive chairman of Palm, where he runs product development. He spent his first few months tweaking the company's product plans. Now he's pushing those plans forward, sometimes from his management seat, sometimes getting into the design work itself. And he spends a fair amount of time working his industry contacts to recruit engineers, software writers, and other tech specialists.

On a typical day, Rubinstein catches up on e-mail and phone calls on an 8:00 a.m. train from San Francisco. At the Mountain View station he hops on a Caltrain shuttle, just another middle-aged engineer in a cotton shirt and jeans, which takes him to Palm's Sunnyvale offices; he arrives around 9. He'll leave Palm between 6:30 and 7 p.m., earlier if he has scheduled meetings in San Francisco. Then he'll have dinner with his wife.

And so far, at least, it looks like that idea of having a personal life wasn't a pipe dream. On Fridays he works from home. He'll spend time in his home office on weekends, but he takes off for long runs and bike rides through San Francisco or Marin County. He spends a few weeks a year at his Mexico digs; they're fully wired, and the IP phone he uses for his main contact number can ring him just about anywhere.

Palm hasn't yet announced any of the products that originated under Rubinstein, although he has tweaked some recently released products and says that quality and reliability are improving. He helped cancel several projects, including an ultrathin laptop just before it was scheduled to ship. He expects the first products completely designed under his watch to begin hitting the market in 2009.

These days, Blank says, Rubinstein is "a product development machine. Steve [Jobs] beat him into becoming this machine, but he doesn't need to be beaten any more; maybe that's why he left. He understands every part of product design, from idea through manufacturing. Everything."

What Rubinstein still has to prove is whether he's a creative genius as well as a brilliant implementer. "The jury is out on that," Blank says. But he adds that he personally has made a big investment in Palm stock.

Everywhere in the world Rubinstein goes, he sees people with iPods. None of them know that this lanky American made the iPod happen. He doesn't have Jobs's instant recognizability, and that's just fine with him.

"As an engineer," he says, "you couldn't ask for any more than what I'm doing. I helped turn Apple around; I helped create the iPod. My role is to make people happy with great products. I'm just a product guy." ❑

iPAD: Jon Rubinstein supervised the construction of his Mexican retreat, a 1500-square-meter villa in a coastal community. He approached the house's construction as though he were putting together a big iPod, finding the best components and making them work together.

PHOTO: MIGUEL GARCIA

Fraunhofer Gesellschaft

TU berlin

The Technische Universität Berlin and the Fraunhofer-Gesellschaft are seeking to appoint a suitable candidate to the position of

Professor (W3) of Hetero Systems Integration
in the Faculty of Electrical Engineering and Computer Science (Faculty IV)

to be exercised in conjunction with the position of

Director of the Fraunhofer Institute for Reliability and Microintegration IZM

in Berlin (as a successor to Prof. Dr.-Ing. Dr.-Ing. E.h. Herbert Reichl). The selected candidate is to commence his or her duties on October 1, 2009.

The Technische Universität Berlin and the Fraunhofer Institute for Reliability and Microintegration seek to maintain their close scientific and personal relationship. Their objective in linking the university professorship with the directorate of the Institute is to foster the practical training of undergraduate and postgraduate students and the efficient transfer of research findings into economically viable products. The Fraunhofer IZM employs a staff of 230 who are engaged in trailblazing research in the field of assembly and packaging technology (systems integration).

The holder of the position will be expected to represent this area of expertise competently in both research and teaching activities. Teaching commitments will include a substantial involvement in the Bachelor and Master Courses of study in Electrical Engineering and Computer Science. Research activities should cover the areas of micro and nano packaging of integrated circuits, reliability of electronic components and systems, and microsystems integration technologies. Applicants should preferably hold appropriate qualifications in several of the specialized fields listed:

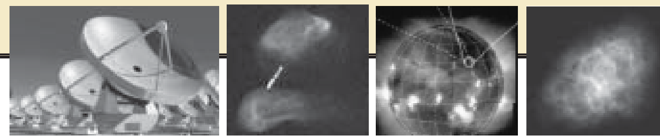
– Packaging of electronic components and systems
– Micro and nano packaging of integrated circuits
– Reliability of integrated structures and systems
– Microsystems integration of components, sensors and actuators
– System-in-package technologies

Applicants must be willing to cooperate on an interdisciplinary basis with other university faculties, non-university research establishments and partners from industry. Experience of a pertinent activity in an industrial enterprise is desirable. Experience of personnel management, the organization of complex projects and the acquisition of research contracts are essential.

Applicants must fulfill the prerequisites for appointment as specified in Section 100 of the Berliner Hochschulgesetz.

The Technical University of Berlin and the Fraunhofer-Gesellschaft have a policy of encouringing a higher proportion of women to engage in research and teaching, and therefore particularly welcome applications from female scientists. Preference will be given to physically handicapped applicants with otherwise equivalent qualifications.

Applications should be submitted together with the usual references (curriculum vitae in table form with photograph, list of publications and lecture programs, copies of testimonials and certificates) by the closing date of September 30, 2008, addressed to the
Technische Universität Berlin
Dean of Faculty IV – Electrical Engineering and Computer Science
Prof. Dr.-Ing. Olaf Hellwich
Sekr. FR 5-1, Franklinstraße 28/29, 10587 Berlin
and to the
President of the Fraunhofer-Gesellschaft
Prof. Dr.-Ing. habil. Hans-Jörg Bullinger
Hansastraße 27c, 80686 München



The ***Atacama Large Millimeter/submillimeter Array*** (ALMA – http://www.alma.cl), an international astronomy facility, is a partnership between Europe, Japan and North America in cooperation with the Republic of Chile. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of Japan by the National Astronomical Observatory of Japan (NAOJ) and on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI). When complete, ALMA will be a world-leading mm/submm radio telescope, enabling transformational observations of the Universe.

The Joint ALMA Observatory (JAO) is seeking two senior engineers to become Managers of the ALMA Antenna and Electronics Groups reporting to the Head of Technical Services. The positions are based at ALMA's Operation Support Facility (OSF) near San Pedro de Atacama and the Array Operation Site (AOS) located at Chajnantor, 5000m altitude.

ANTENNA GROUP MANAGER – (CL00018)

This position will be responsible for day-to-day operation and maintenance of all antennas and associated equipment (e.g. optical pointing telescopes, nutators), developing the required maintenance schedules and programs and, thereafter, monitoring their execution. University degree in Electrical or Mechanical Engineering or equivalent is required.

ELECTRONICS GROUP MANAGER – (CL00020)

This position will be responsible for day-to-day maintenance of front-end instrumentation packages including cryogenics, back-end electronics and communication packages, local oscillator systems, optical fiber network, and digital correlators. University degree in Electrical Engineering or equivalent is required.

Both positions also require at least 6 years of relevant field engineering experience in similar large research and/or high technology projects; strong managerial and leadership skills, with a demonstrated ability to lead, supervise, mentor and evaluate staff; creative thinking and problem solving skills, capacity to work under pressure and excellent interpersonal skills. Excellent verbal and written communication skills in English are essential, together with at least a working knowledge or willingness to learn Spanish.

ALMA international staff will be recruited as employees of either AUI/NRAO or ESO. AUI/NRAO and ESO offer attractive remuneration packages including a competitive salary, comprehensive social benefits, and financial support in relocating families. Furthermore, an expatriation allowance as well as some other allowances may be added. For further details and requirements and to download an application form, please consult our homepages: **NRAO/AUI** at **http://www.nrao.edu or ESO at http://www.eso.org**.

If you are interested in working in areas of frontline technology and in a stimulating international environment, please send your application in English to the Personnel Office, stating the position code **CL00018 – AG Manager** or **CL00020 – EG Manager**. For NRAO, apply to **NRAO, 520 Edgemont Road, Charlottesville, VA 22903** or electronically to **resumes@nrao.edu**. For ESO, please apply on-line at **https://jobs.eso.org/**. Review of the applications will begin September 15, 2008; however we will accept applications until the position is filled. All applications should include the names of four individuals willing to serve as professional references for the applicant.

NRAO/ESO are equal opportunity employers. The post is equally open to suitably qualified male and female applicants.

Universität Stuttgart

Universität Stuttgart, Germany, invites applications for a

Full Professorship (W3) for Radio Frequency Technology

in the Department of Computer Science, Electrical Engineering and Information Technology. The appointee will head the institute of the same name.

This call for application is subject to approval by the Ministry of Science, Research and the Arts of Baden-Württemberg.

The professor contributes to undergraduate and graduate teaching in the degree programs of electrical engineering and information technology as well as in the international Master program "Information Technology".

The main research areas at the institute are:
- Components and systems of wireless communication
- Wave propagation models and localization techniques for mobile communications
- Numerical methods for the computation of electromagnetic scattering problems
- Radio navigation systems
- Antennas and field measurement techniques
- Electromagnetic compatibility

The acquisition of research funding is expected.

Applicants are expected to have excellent scientific skills in at least two of the above mentioned topics as well as didactic qualifications. Experience in industrial research is desired.

The requirements for employment listed in § 47 Baden-Württemberg university law apply; in case of first appointment as professor employment can be limited to three years.

Applicants are asked to send their CV and accompanying documents to the Dean (Dekan der Fakultät 5, Universität Stuttgart, Pfaffenwaldring 47, 70550 Stuttgart, Germany) before October 30, 2008.

Universität Stuttgart wishes to increase the proportion of female academic staff and, for this reason, especially welcomes applications from women. Severely challenged persons will be given preference in case of equal qualifications.

the data

By PRACHI PATEL-PREDD

Data Breaches

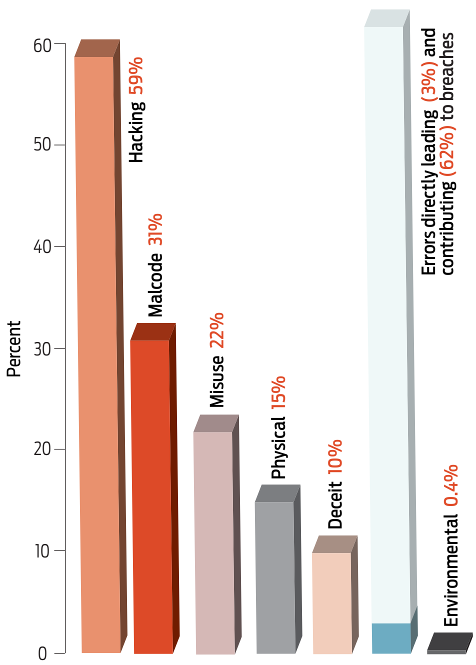
WILLIE SUTTON famously said that he robbed banks because that's where the money was. You might think that today's thieves would do the same, possibly by hacking into ATM machines. Yet it turns out that financial services account for only 14 percent of data breaches, while 20 percent are in the food and beverage industry.

That's just one surprising statistic in a new global study of some 500 security breaches handled by Verizon Business's RISK Team between 2004 and 2007, involving more than 230 million data records. Verizon's report sorts attacks into seven categories. Hacking is, unsurprisingly, a cyber-criminal's favorite weapon. Errors, such as incorrect network settings, directly led to just 3 percent of the breaches, but by giving bad guys a leg up they ended up contributing to many more.

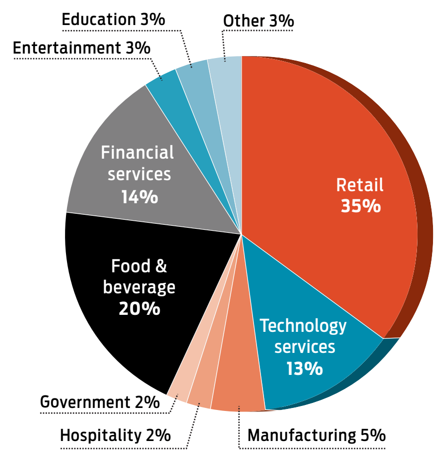
In a disturbing trend, in the study's first year only 8 percent of all attacks involved partner organizations, such as vendors and customers, but by 2007 fully 44 percent did. Twenty-four percent of all attacks originating outside an organization came from IP addresses in Eastern Europe. Such addresses can't always lead to a particular attacker's exact location, but some clear patterns emerge. For example, attacks on point-of-sale systems were frequently traced back to Eastern Europe and Russia, while Web graffiti and other defacements often originated in the Middle East.

The full report is available at http://www.verizonbusiness.com/resources/security/databreachreport.pdf. ❑

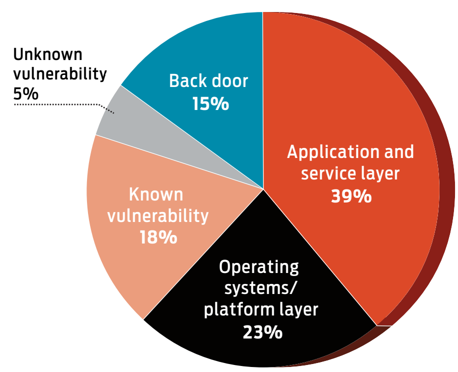
THREAT CATEGORIES



INDUSTRIES REPRESENTED



BREAKDOWN OF HACKING



Percentage of attacks from outside an organization 73

Percentage of attacks implicating business partners 39

Percentage of attacks from internal sources 18

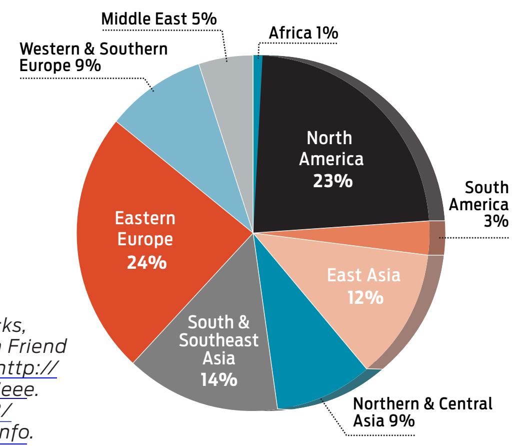
Median number of records compromised from external attacks 30 000

Median number of records compromised from partner attacks 187 500

Median number of records compromised from internal threats 375 000

Percentage of internal attacks by IT admin 50

LOCATION OF ATTACKING IPs



For more on insider cyberattacks, see "When Friend Is Foe" at http://spectrum.ieee.org/sep08/moredatainfo.

Source: "2008 Data Breach Investigations Report." Verizon Business RISK Team