IEEE Spectrum
THE MAGAZINE OF TECHNOLOGY INSIDERS
SPECTRUM.IEEE.ORG
8.11

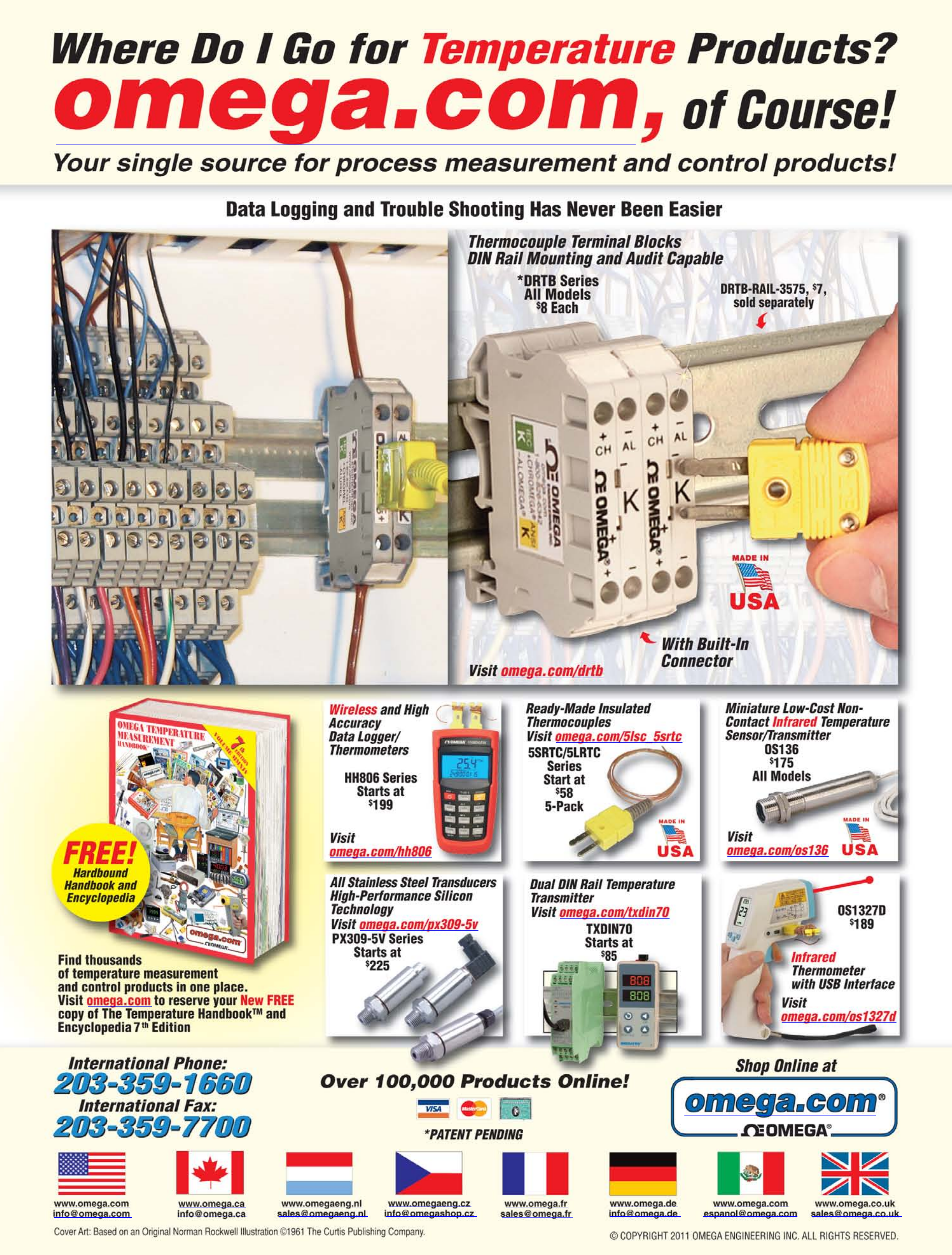
# ROBO-WARRIORS

THE REMOTELY CONTROLLED VEHICLES OF IRAQ AND AFGHANISTAN WILL EVENTUALLY GIVE WAY TO **FULLY AUTONOMOUS FIGHTING MACHINES**

**THE SMALLEST SPACECRAFT** WAS LAUNCHED IN MAY, AND IT'S 4 CENTIMETERS LONG

**HIGH-TECH SONARS** REVEAL CITY-SIZE SCHOOLS OF FISH

IEEE


Where Do I Go for Temperature Products?
omega.com, of Course!
Your single source for process measurement and control products!
Data Logging and Trouble Shooting Has Never Been Easier
Thermocouple Terminal Blocks
DIN Rail Mounting and Audit Capable
*DRTB Series
All Models
$8 Each
DRTB-RAIL-3575, $7,
sold separately
MADE IN USA
With Built-In Connector
Visit omega.com/drtb
FREE! Hardbound Handbook and Encyclopedia
Find thousands of temperature measurement and control products in one place. Visit omega.com to reserve your New FREE copy of The Temperature Handbook™ and Encyclopedia 7th Edition
Wireless and High Accuracy Data Logger/ Thermometers
HH806 Series
Starts at
$199
Visit omega.com/hh806
Ready-Made Insulated Thermocouples
Visit omega.com/5lsc_5srtc
5SRTC/5LRTC
Series
Starts at
$58
5-Pack
MADE IN USA
Miniature Low-Cost Non-Contact Infrared Temperature Sensor/Transmitter
OS136
$175
All Models
Visit omega.com/os136
MADE IN USA
All Stainless Steel Transducers High-Performance Silicon Technology
Visit omega.com/px309-5v
PX309-5V Series
Starts at
$225
Dual DIN Rail Temperature Transmitter
Visit omega.com/txdin70
TXDIN70
Starts at
$85
OS1327D
$189
Infrared Thermometer with USB Interface
Visit omega.com/os1327d
International Phone:
203-359-1660
International Fax:
203-359-7700
Over 100,000 Products Online!
*PATENT PENDING
Shop Online at
omega.com®
OMEGA®
www.omega.com info@omega.com
www.omega.ca info@omega.ca
www.omegaeng.nl sales@omegaeng.nl
www.omegaeng.cz info@omegashop.cz
www.omega.fr sales@omega.fr
www.omega.de info@omega.de
www.omega.com espanol@omega.com
www.omega.co.uk sales@omega.co.uk
Cover Art: Based on an Original Norman Rockwell Illustration ©1961 The Curtis Publishing Company.
© COPYRIGHT 2011 OMEGA ENGINEERING INC. ALL RIGHTS RESERVED.

ieee spectrum

volume 48 number 8 international

8.11

26



44

COVER: NOEMOTION

THIS PAGE: TOP, NOEMOTION; BOTTOM, FRED BAVENDAM/GETTY IMAGES



ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page


We've just made reaching
your goals easier than ever.
10.5
MATERION
Before.
After.

ieee spectrum

volume 48 number 8 international

8.11


## UPDATE



## OPINION

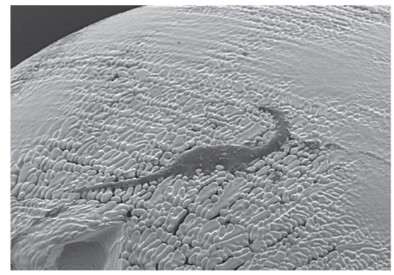


## DEPARTMENTS



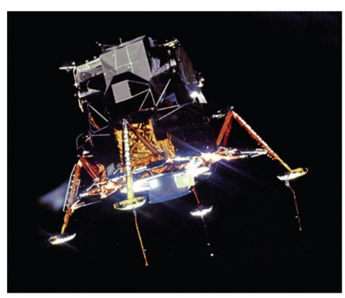
## SPECTRUM.IEEE.ORG AVAILABLE 1 AUGUST

### The Art of Failure



Sometimes art is accidental. At IEEE's 18th annual International Symposium on the Physical and Failure Analysis of Integrated Circuits, held 4 to 7 July in South Korea, participants submitted pictures of surreal and spectacular chip failures in a competition for the most affecting image. First place went to this charming dinosaur silhouette, which is actually a patch of lead on the surface of a ball of tin and lead solder.

## THEINSTITUTE.IEEE.ORG AVAILABLE 5 AUGUST



**LUNAR MODULE EARNS MILESTONE** The Grumman lunar module was the first vehicle to land a person on an extraterrestrial body—the moon. IEEE is recognizing it with a Milestone in Electrical Engineering and Computing.

**LATEST EDITION OF NATIONAL ELECTRICAL SAFETY CODE**
Learn about the 2012 National Electrical Safety Code, which is revised every five years and published exclusively by IEEE. The code sets the U.S. ground rules for the practical safeguarding of people during the installation, operation, and maintenance of electric supply and communication lines and associated equipment.

**SUSTAINABLE COMMUNICATION CONFERENCE** The 2011 IEEE Third Latin American Conference on Communications, to be held 24 to 26 October in Belém, Brazil, will focus on sustainable communications for a green world.

## ONLINE WEBINARS & RESOURCES

AVAILABLE AT http://spectrum.ieee.org/webinar

**18 August: Simulation of Electrodeposition Processes Using COMSOL**

**Smart-Grid Control Systems: Moving Towards a Self-Healing Grid**

**The Insight You Want, the Data You Need: Transforming Insights Into Action**

**Model-Based Solutions to the Code Maintenance Nightmare—Tackling Key Development Headaches**

**Acoustics Simulation in Microphones, Mobile Devices, and Hearing Aids Using COMSOL**

**Real-Time Matters! Timing and Performance Analysis for Embedded Systems**

**Effectively Managing AUTOSAR Development**

**Digitizing the Power Grid: Fundamentals of Smart Grid Sensing and Analytics**

**Using MATLAB to Simulate and Optimize Multiphysics Designs**

**Parameter Estimation and Model Validation of Generator/ Excitation Systems**

**Kinetis ARM Cortex-M4 MCUs: The Inside Story**

**A Smart Approach to Maximizing ROI in Consumer Electronics Innovation**

**New product release library:** http://spectrum.ieee.org/static/new-product-release-library

CLOCKWISE FROM TOP LEFT: KOHN PEDERSEN FOX ASSOCIATES; RUDOLF A. SIA; NASA

SUSTAINABLE FORESTRY INITIATIVE
Certified Chain of Custody
Promoting Sustainable Forest Management
www.sfiprogram.org

Printed with inks containing soy and/or vegetable oils

**IEEE SPECTRUM** (ISSN 0018-9235) is published monthly by The Institute of Electrical and Electronics Engineers, Inc.  3 Park Avenue, New York, NY 10016-5997, U.S.A. The editorial content of IEEE Spectrum magazine does not represent official positions of the IEEE or its organizational units. Canadian Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40013087. Return undeliverable Canadian addresses to: Circulation Department, IEEE Spectrum, Box 1051, Fort Erie, ON L2A 6C7. Cable address: ITRIPLEE. Fax: +1 212 419 7570. INTERNET: spectrum@ieee.org. ANNUAL SUBSCRIPTIONS: IEEE Members: $21.40 included in dues. Libraries/institutions: $399. POSTMASTER: Please send address changes to IEEE Spectrum, c/o Coding Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, NJ 08855. Periodicals postage paid at New York, NY, and additional mailing offices. Canadian GST #125634188. Printed at 120 Donnelley Dr., Glasgow, KY 42141-1060, U.S.A. IEEE Spectrum circulation is audited by BPA Worldwide. IEEE Spectrum is a member of American Business Media, the Magazine Publishers of America, and Association Media & Publishing. IEEE prohibits discrimination, harassment, and bullying. For more information, visit http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html.



ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

# back story

## A 3-D Me

EVERY NOW and then our photo editor, Randi Silberman Klett, finds herself on the other side of the camera lens. But she wasn't expecting that to happen in a gritty workshop in Brooklyn, N.Y.

It all started with an article draft on how to set up a workshop for electronics [Hands On, "DIY Essentials," in this issue]. Klett needed to get photos for the story and "knew instantly who to call," she says—the folks at NYC Resistor, a community-owned hobbyist, tinkerer, and educational space in downtown Brooklyn.

On the day of the shoot, a typically motley crew was on hand doing the usual sort of work, in this case cutting wood for a portable pool to fit in a pickup truck. (Who hasn't wanted one of those?) In a front room, meanwhile, programmers quietly tapped away on keyboards, unperturbed by the shrieks of a circular saw.

As Klett set up her camera equipment, NYC Resistor cofounder Bre Pettis peeked in to ask if anyone wanted to be scanned in 3-D. Pettis, who once contributed an article to *IEEE Spectrum* about an automated bartender, heads MakerBot Industries, which sells kits for desktop "printers" that produce 3-D objects.

Klett immediately volunteered to be scanned. Moments later, she had cornstarch all over her face; it turns out that the Polhemus FastScan Scorpion laser scanner sees light colors best.

A young man named Jonathan Monaghan warned Klett to keep her eyes shut and then scanned her face, head, and shoulders. Spectators watched as the scan slowly filled in on an adjacent computer screen. Klett's curly hair presented a particular challenge; a second round of scanning was needed. Days later, the MakerBot would construct the actual bust, which now sits in Klett's office, next to other memorabilia of photo shoots past.

After the scan, a cornstarch-free Klett returned to her photo shoot. There was a brief moment of panic when it seemed that one of the key items on her list was unavailable. But then Raphael Abrams, a 32-year-old freelance designer and electrical engineer, looked up from his laptop. "A logic analyzer?" he asked. "I have one in my bag." ❑

FROM TOP: BRE PETTIS (2); RANDI SILBERMAN KLETT

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 Data is in *IEEE Spectrum*, Vol. 48, no. 8 (INT), August 2011, p. 56, or in *IEEE Spectrum*, Vol. 48, no. 8 (NA), August 2011, p. 64.


Name
Dr. Christian Altenbach, Certified LabVIEW Associate Developer
Job Title
Research Ophthalmologist
Area of Expertise
Biophysics
LabVIEW Helped Me
Analyze and visualize data interactively using custom algorithms
Latest Project
Mapping molecular structure changes during activation of the light receptor, rhodopsin
NI LabVIEW
LabVIEW makes me better because I can
PROGRAM
the way I think

# contributors

**MARK ANDERSON,** who wrote about the Wikipedia entry on the "Shakespeare authorship question" [p. 22], is a regular contributor to *IEEE Spectrum* and the author of *Shakespeare by Another Name: The Life of Edward De Vere, Earl of Oxford, The Man Who Was Shakespeare* (Gotham, 2005).

**GEORGE HADJIPANAYIS** and **ALEXANDER GABAY** have worked for a decade to make stronger magnets. Hadjipanayis chairs the physics and astronomy department at the University of Delaware, where Gabay is a research scientist. In "Magnet Makeover" [p. 32], they explain their recent research with magnetic nanoparticles. While other nanoparticles are relatively easy to produce ("You close your eyes and you make it," says Hadjipanayis), magnetic materials are tricky; even plain iron, when broken down into nanoscale bits, is highly reactive. "It oxidizes so fast, it catches fire," he says.

**NICHOLAS MAKRIS,** author of "Unidentified Floating Objects" [p. 44], worked as a marine rescuer in Boston Harbor during college. Between calls, he often listened to one old-timer—who turned out to be inventor and MIT professor Harold "Doc" Edgerton—tell of his adventures with Jacques Cousteau. Intrigued, Makris sought a spot on an expedition with MIT's Laboratory for Undersea Remote Sensing, a fateful decision that led him to his current position as the lab's director.

**NOEMOTION** of Prague—the partnership of Marek Denko and Peter Sanitra—is known for its ultra-realistic 3-D animation. The foreground and sky in their image on our cover are real, but they created the robotic tank from scratch. "NoEmotion's use of light and detail is akin to how a photographer or cinematographer sees a scene," says Senior Art Director Mark Montgomery. "It's what elevates their work to the top level of 3-D artistry."

**MASON PECK,** author of "Chips in Space" [p. 38], is no stranger to unorthodox spacecraft designs. A professor of mechanical and aerospace engineering at Cornell University, he's studied magnetic docking mechanisms and tractor beams. He thinks that mass-produced spacecraft, each made of a single microchip, could be truly revolutionary. "They may be the way we'll finally democratize space exploration," Peck says.

**JOEL B. PREDD,** an associate engineer at the Rand Corp., in Pittsburgh, created The Data page for this issue [p. 56]. A Ph.D. in information sciences and systems from Princeton, he has published papers in various IEEE journals, but this is his first effort for *IEEE Spectrum*. He is pleased to share these pages with his wife, Contributing Editor Prachi Patel.

**LORA G. WEISS** is a lab chief scientist at the Georgia Tech Research Institute. In this issue, she writes about the challenges of designing smarter military robots [p. 26]. Her Ph.D. work on signal processing for underwater systems first got her interested in robotics. "Signals don't propagate well underwater, so you can't rely on a human operator for control," she says. "I quickly realized that the vehicles would have to start making decisions on their own."



CLOCKWISE FROM TOP LEFT: PENNY LEVERITT; CORNELL UNIVERSITY; PRACHI PATEL; GEORGIA INSTITUTE OF TECHNOLOGY; MIT LABORATORY FOR UNDERSEA REMOTE SENSING



spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®


Name
Hector Guajardo Betancourt, Certified LabVIEW Architect
Job Title
Automated Test and Control Engineer
Area of Expertise
Manufacturing Test
LabVIEW Helped Me
Reduce test time by more than 10X
Latest Project
Building a vision-based inspection system for washing machine drums
NI LabVIEW
LabVIEW makes me better because I can deliver multiple
PROJECTS
on time, on spec, and on budget

# spectral lines

PAT SULLIVAN/AP PHOTO

## Saving Smart Meters From a Backlash

A BIG TECHNOLOGICAL change is inspiring fear and loathing in the masses. The peril is not a vaccine, a new variant of *E. coli*, or mishandled nuclear reactors. The peril is the smart meter. Just as activists once cried, "Ban the bomb!" they are now crying, "Ban the smart meter!"

Sometime last year, Pacific Gas and Electric Co. replaced my old meter with a smart meter, which sports a tiny antenna that broadcasts information wirelessly. PG&E supplied me with the meter at no extra charge. The smart meter is a digital computer that measures the flow of gas and electricity into my house and reports on my usage to a central database, which I can, at least theoretically, access (when PG&E finally gets around to letting me do so).

The meter gives off ultrahigh-frequency radio waves, but then so do cellphones. Across the United States, about 20 million similar meters have been installed. By 2015, Chris King, chief regulatory officer of eMeter Corp., expects 25 percent of utility meters to go smart, with millions more smart meters to be installed between now and 2020.

The smart meter promises to manage my electricity more efficiently. Yet the device is provoking the most organized opposition to a technological artifact since vaccines were tagged (wrongly) with causing autism in kids. In the superstates of California and Texas, as well as Connecticut, resistance to smart meters is so widespread that temporary or permanent bans on these devices have been either imposed or debated.

Here's the difference between smart meters and cellphones for people too confused or paranoid to observe this for themselves: I don't hold the smart meter to my ear or carry it around in my pocket. It's stuck in the ground outside my house. Smart meters are not going to increase my chances of contracting brain cancer, but my frustration with people who believe that is definitely raising my blood pressure.

Radiation isn't the only complaint. Smart meters store much of customers' personal data on electricity usage, which could violate their privacy if not safeguarded. And new meters have spawned complaints of inaccuracy in Texas and California. These charges have been debunked by utilities, but fears of inaccurate metering are fanned by the introduction of meters alongside new rate plans, making straight-up comparisons with the past difficult.

To be sure, the brouhaha over smart meters is a reminder that new technologies require patient explanations or clever promotion in order to win acceptance. Once the virus of suspicion spreads, even an electricity meter begins to look menacing. In California, PG&E, which has one of the nation's most aggressive rollout plans, has asked its government regulator to allow customers an opt-out plan in order to undercut opposition.

PG&E's request, which regulators could approve by September, would charge customers for the privilege of dumbing down their smart meters by having the antennas switched off. To have this done, the customer would pay a one-time charge of US $135 and then a monthly fee of $20 to cover what PG&E says are the costs of humans reading stupid meters. In economic terms, these charges are disincentives, yet PG&E estimates that at least 145 000 customers will choose to opt out. Maine has also decided to permit customers to choose to have their meters' transmitters turned off for a one-time cost of $20 and an annual fee of $120. More states may do the same.

Refusing a new technology is a democratic right, of course, but in this case it reflects a shoddy way of thinking about the electricity system. Opt-outs, in short, carry significant social costs because of network effects. The less folks use smart meters, the more everyone ends up paying for power.

Utilities are chastened but not defensive in their response to frustration, anger, and confusion over smart meters. A coalition of utilities and meter makers has formed a national organization called the SmartGrid Consumer Collaborative to improve public understanding of new metering technology.

Individual utilities are also learning lessons from the debacle in California. The Arizona Public Service Co. is wooing customers with information about the benefits of smart meters rather than depending on the presumption that "new" is always "improved."

Better promotion of smart meters may not be enough. Once it gets amplified across the Web, a belief can be hard to eradicate, even when it's wrong. Smart meters could well become the big new fear in a society where the endless embrace of new technologies invariably coevolves with a nagging suspicion of hazards too horrible to discuss.

—G. Pascal Zachary

*G. Pascal Zachary is a professor of practice at the Consortium for Science Policy & Outcomes at Arizona State University and a frequent contributor to* IEEE Spectrum. *A longer version of this article appeared on our website in June.*

# update

more online at spectrum.ieee.org

**SKYLINE FROM SCRATCH:** Cisco plans to make Songdo, about 50 kilometers from Seoul, smarter than the average city. The company hopes to strike similar deals with other cities.
PHOTO: KOHN PEDERSEN FOX ASSOCIATES

## Cisco Bets on South Korean Smart City

Songdo aims to be the most wired city on Earth

AN AIRY penthouse on the 63rd floor of a brand new apartment tower affords a marvelous view of Songdo, mankind's latest attempt to build a "city of the future." This half-finished South Korean city, built on landfill dumped into the Yellow Sea at Incheon, is currently a patchwork of gleaming towers and empty plots of land. But when the 607-hectare Songdo IBD (International Business District), which forms the heart of the city, is complete in 2018, it will house about 65 000 people in what developers claim will be the greenest, most wired city in the world.

Because the city's planners were building a metropolis from scratch, they were able to configure it to meet the demands and challenges of our modern world. Gale International, the primary developer behind the business district, constructed towers that meet strict standards for green buildings, laid out neighborhoods smartly, and created an urban oasis modeled on New York City's Central Park. The South Korean government did its part, putting in a robust public transit network and a state-of-the-art water recycling system.

But what's a modern city without ubiquitous broadband Internet connections?

To that end, Cisco Systems has stepped in with an investment of US $47 million that promises to wire Songdo from top to bottom. The effort is part of a strategic shift embodied by Cisco's Smart+Connected

# update

**MISSION CONTROL:** Engineers demonstrate Cisco's government services operation center.
PHOTO: LIPO CHING/MCT/LANDOV

Communities initiative. "We believe the biggest challenge for the 21st century is urbanization and sustainability," says Anil Menon, president of the new business unit. The company estimates that smart cities offer a $13 billion market opportunity over the next three to five years and says it is working with more than 20 cities worldwide on projects similar to Songdo.

The 63rd-floor penthouse is a showcase for Cisco's vision of the new urban home. A screen on one wall displays a menu from which lights, music, temperature, and window blinds are easily controlled. In another room, on another screen, Munish Khetrapal, Cisco's director of solutions in Asia, holds forth from his Singapore office via the company's TelePresence videoconferencing system. Khetrapal rhapsodizes about a time when every apartment in Songdo will be similarly equipped. "We're trying to make this equipment part of the standard system," he says. "When you turn on the tap you have water to drink, and when you turn on the TelePresence you have a conference."

Because Cisco joined the Songdo project only in 2009, five years after buildings started rising above the landfill, most apartments don't yet have the wired wonders found in the penthouse. But Cisco is now retrofitting some existing buildings and is working with developers to build its networking technology into new residences.

Khetrapal believes these high-tech apartments will change people's lives. He says that soon each new apartment will come with TelePresence capabilities; the resident will choose whether to pay the equivalent of $10 per month for an unlimited use plan—and whether to pay more money to various providers of remote services. For example, a resident could start her day with a live yoga class; later her child could get one-on-one English lessons from a teacher across the world. (These services wouldn't require upgraded Internet service: South Korea already has the fastest Internet connections in the world, with an average download speed of 14 megabits per second.) Cisco expects to install more than 10 000 TelePresence units in Songdo by 2018.

These domestic offerings are just the first step toward the city that Cisco envisions. The company wants to link energy, telecom, traffic monitoring, and security systems into one intelligent network.

"We want to build an IP-based platform that is open," says Menon. "Imagine iTunes, but for a city," he muses. "We'll build the platform, then local entrepreneurs build the applications." A utility company could give cheaper rates to residents who agreed to let the company turn off their appliances during energy peaks; a car company could give drivers real-time traffic information and directions, automatically pay their tolls, and send emergency messages to the police and hospitals in the event of an accident.

Next year, Cisco will move into a two-story operations center in the Northeast Asia Trade Tower, the new Songdo skyscraper that is South Korea's tallest building. The company hopes this operation center will one day buzz with representatives of the companies and public entities that are running applications on its network.

It's not yet clear what applications will be tried out—or if Songdo citizens will actually want all these high-tech amenities. But Cisco thinks it's fine even if some things don't work out. Songdo, says Menon, is a "living lab for the 21st century." And as any scientist will tell you, labs see both successes and failures.

—Eliza Strickland

NELSON CHING/BLOOMBERG/GETTY IMAGES

## Cool From Coal

Climate scientists in Massachusetts and Finland conclude that the 1998 to 2008 pause in the rise in global temperature can partly be attributed to Chinese coal plants. Coal consumption increased rapidly at the turn of the century—26 percent from 2003 to 2007. And China accounts for 77 percent of that increase. (It took coal consumption 22 years to make that leap prior to 2003.) Sulfur emitted from burning coal has a short-lived cooling effect. Combine that effect with solar cycles and natural atmospheric phenomena like El Niño and the turn-of-the-century temperature pause makes sense.

**84 PERCENT** Reduction in the amount of energy needed to reset a fibrillating heart using a special sequence of electric-field pulses. Its inventors in Germany and New York state hope to use the sequence to make less-damaging defibrillators.

# Japan Faces Post-Fukushima Power Struggle

Crisis transforms renewable energy bill into an antinuclear symbol

On the morning of 11 March 2011, Japan's cabinet forwarded a bill to parliament (known as the Diet) that would modestly expand support for renewable energy. A few hours later, an earthquake struck northeastern Japan. The tsunami and nuclear crisis it unleashed transformed that noncontroversial piece of legislation into a vanguard of efforts to radically redraw Japan's energy policy.

"This renewable energy law is a symbol of energy policy change. It is indispensable," says Tetsunari Iida, executive director of the Tokyo-based Institute for Sustainable Energy Policies and a long-time critic of nuclear power.

The driving force behind the bill is Prime Minister Naoto Kan, whose popularity plummeted after Tokyo Electric Power Co. (TEPCO) lost control of the Fukushima Daiichi nuclear power plant and then misled the public about the danger. Since then, however, Japan's fifth prime minister in as many years has been fending off resignation calls by challenging Japan's nuclear industry. In May, Kan demanded closure of the 3.5-gigawatt Hamaoka nuclear power plant, a coastal station with limited tsunami walls, and vowed to remake Japan's energy policy with renewables as a central pillar. In late June, Kan canceled the Diet's summer break, extending the session by 70 days to push through the renewables bill (along with a compensation package for Fukushima Daiichi's neighbors and a budget bill).

Kan's initiative could be a major shift for Japan. The country's nuclear-focused Basic Energy Plan called for 14 new reactors by 2030, which would nearly double nuclear generation and make it about 50 percent of Japan's electricity supply. Last year, despite being the world's third-largest economy, the country invested just US $3.3 billion in alternative energy, placing it 11th among the G-20, according to a March 2011 ranking by the Pew Charitable Trusts.

The bill before the Diet would build on Japan's sole renewable bright spot: a recent jump in solar power driven by a feed-in tariff (FIT) law introduced in 2009. The law required utilities to pay 48 yen per kilowatt-hour ($0.59/kWh) for solar energy delivered to the grid from residential rooftops, and half that for surplus generation by businesses and schools. Thanks to the tariffs, solar installations grew by 111 percent last year.

The 2011 proposal (the "Bill on Special Measures Concerning Procurement of Renewable Energy Sourced Electricity by Electric Utilities") would add FITs for other forms of renewable generation starting from 2012, including a 20 yen FIT for wind power and a 15 yen FIT for geothermal. Regulators, meanwhile, have adjusted the solar FIT to 42 yen for homes and 40 yen for institutions. Those price premiums could inspire up to 148 GW of renewable energy by 2030, according to projections by Japan's Ministry of the Environment.

Equipment firms such as Toshiba and Mitsubishi Heavy

**LONELY AT THE TOP:** Japanese prime minister Naoto Kan is fending off calls for his resignation by challenging the country's nuclear industry.

LEFT: YOSHIKAZU TSUNO/AFP/GETTY IMAGES; RIGHT: NASA/JPL/SSI

*news brief*

**Septillion-Joule Storm**

Scientists working with data from the Cassini space probe have been studying a violent, seven-month long, planet-spanning storm on Saturn. As of mid-July, the storm had covered 4 billion square kilometers, or about eight times the surface of Earth. The space probe is detecting up to 10 lightning strikes each second, contributing to a calculated storm energy of 1 septillion ($10^{24}$) joules during the storm's first three months.



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

**1 MILLION** Number of ARM processor cores to be integrated into the SpiNNaker computer. The machine, under construction at the University of Manchester, in England, will be able to simulate about 1 percent of a human brain.

# update

Industries are ramping up their renewable offerings as they downgrade expectations for nuclear reactor construction. But Japan's 10 regional electric utilities are raising concerns about costs that will be passed on to consumers, and the influential Keidanren industrial federation is opposing the bill. Powerful Diet members from Kan's Democratic Party of Japan and the opposition Liberal Democratic Party, echoing industry's concerns, were blocking debate on the bill as *IEEE Spectrum* went to press.

Editorials by the *Asahi Shimbun* see self-interest behind the opposition. The popular Japanese daily wrote on 21 June that expanded FITs will "demolish the traditional assumption that electricity is produced at large power plants" and thus "shake up" the status quo in which "utilities have been monopolizing regional markets." The paper attributes opposition to the legislation to utilities' "strong influence" on Japan's political parties.

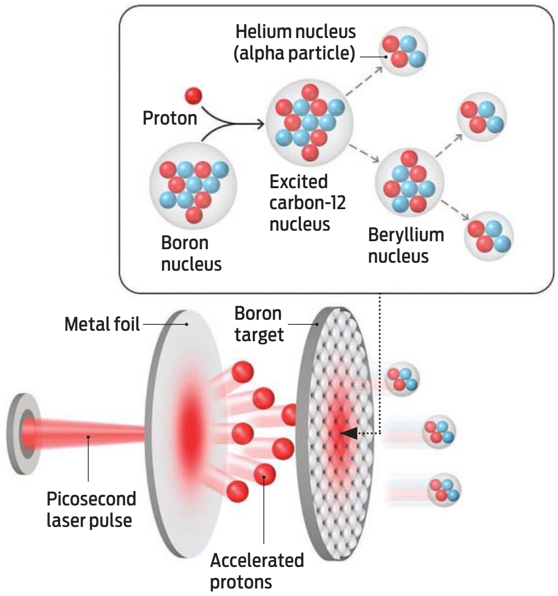
Renewables advocate Iida says the utilities are right to suspect a challenge to their monopolies. His institute projects that by 2020, renewable power and energy efficiency moves could phase out at least three-fifths of Japan's nuclear generation and reduce oil and coal-fired generation at the same time. His own plan includes 40 GW of wind turbines and 81 GW of solar panels. That's more wind power than was installed globally in 2010 and twice the photovoltaics currently operating worldwide.

Such a shift would require substantial grid upgrades. The massive fluctuating power flows of solar and wind installations would overwhelm the utilities' weakly connected regional grids, epitomized by the tiny 1.2-GW connection between TEPCO's 50-hertz grid and the 60-Hz grids to its west.

Targeted investments can fix individual bottlenecks. Iida's plan, for example, calls for up to 9 GW of new frequency converter stations to bridge Japan's frequency divide. But readying Japan for reliance on renewable energy will take a more radical overhaul than just that, says Iida. What Japan needs is the transmission structure emerging in renewables leaders like Germany: grids with robust regional interconnections, owned by independent transmission companies and operating under national rules that prioritize renewable generation.

Iida's ideas are controversial, but post-Fukushima, they are no longer unspeakable. This spring Kan even floated the idea of deregulating the power industry by splitting power generation and transmission. No wonder Japan's utilities are having a fit.

—Peter Fairley




## A Fusion Thruster for Space Travel

Someday, space agencies might fling satellites through space on mere grams of fuel. How will they do it? Fusion. In a fusion reactor scheme conceived by John J. Chapman, a physicist and electronics engineer at NASA's Langley Research Center, in Hampton, Va., a commercially available benchtop laser starts the reaction: It zaps a two-layer target with a beam that generates a teravolt-per-meter electric field. This sets off a chain reaction in which protons are explosively ejected from the metal in the target's first layer and then strike the second layer, a film of boron-11.

For each boron atom that one of these energetic protons strikes, three alpha particles are released, each with a kinetic energy of 2.9 megaelectron volts. Electromagnetic forces push the target and the alpha particles in opposite directions, and the particles exit the spacecraft through a nozzle, providing the vehicle's thrust. Even at 50 percent efficiency, burning off 40 milligrams of the boron fuel would deliver a gigajoule of energy, according to Chapman.

*—Willie D. Jones*

GEORGE RETSECK

# Photon Recycling Breaks Solar Power Record

## Strange as it sounds, a better light emitter is a better energy producer

BY CREATING a solar cell that also does a good job of emitting light, a California start-up has produced the new efficiency record holder for a solar cell with a single *p-n* junction. When combined with a novel manufacturing method, the technology will be a path toward solar power at a cost competitive with that of fossil fuels, according to its maker, Santa Clara–based Alta Devices.

In June, at the 37th IEEE Photovoltaic Specialist Conference, in Seattle, researchers from Alta reported the creation of a gallium-arsenide cell with an efficiency of 28.2 percent. That beats the previous record of 26.4 percent, which itself was the first improvement in years over the previous 26.1 percent.

Key to achieving the record was building a solar cell that was good not only at taking in light but also at letting it out. One factor in such external fluorescence extraction—a measure of how much incoming light comes back out—is a process called photon recycling. When a photon in sunlight is absorbed in a photovoltaic material, it splits into an electron and a hole. The electrons that pass out of the cell can be used as electricity, but many of them are lost in the semiconductor when they recombine with holes to produce either waste heat or new photons. By carefully growing a high-quality, single-crystal film of gallium arsenide, the researchers managed to ensure that more than 90 percent of the recombinations would result in new photons. Those recycled photons can split and recombine into new photons repeatedly, giving the light more opportunities to either create usable current or escape.

Eli Yablonovitch, an engineering professor at the University of California, Berkeley, and a cofounder of Alta, admits that making a solar cell good at giving off light sounds counterintuitive. But better light extraction is an indirect indicator of how efficiently the cell is using photons. "A great solar cell has to be a great LED," he says.

Cells with higher external fluorescent efficiency also have higher voltage. The previous record holder for efficiency produced 1.03 volts; the Alta device reached 1.11 V. "In 12 months, a technology that had been essentially stagnant for decades had increased by 8 percent," Yablonovitch says. The theoretical limit is 1.15 V.

The device is nearer the theoretical limit for conversion efficiency, too. The maximum is 33.5 percent. "We can see a path to 30 percent with our same design right now," says Christopher Norris, CEO of Alta.

Yong-Hang Zhang, director of the Center for Nanophotonics at Arizona State University, thinks it should be possible to build practical solar cells with better than 30 percent efficiency "by texturing the surface, removing the substrate, and adding a highly reflective reflector at the back of the cell," he says.

While gallium arsenide is naturally better at converting light to electricity than the chief contenders, it tends to be more expensive. Alta solves this problem by using a process called epitaxial liftoff, developed by Yablonovitch, that minimizes the amount of GaAs used.

Alta plans to produce samples of its solar cells sometime this year and expects to have early commercial shipments by late next year, Norris says. The company has raised US $130 million to develop its production process.

—NEIL SAVAGE

*A version of this article appeared online as "Solar Cell Breaks Efficiency Record."*

*news brief*

**Please Drink the Water**

A Siemens pilot plant in Singapore has demonstrated a way of using electric fields to turn seawater into drinking water using half the energy of today's most common method, reverse osmosis. The field pulls ions in the seawater through membranes, captures them, and transports them away, leaving a stream of freshwater.

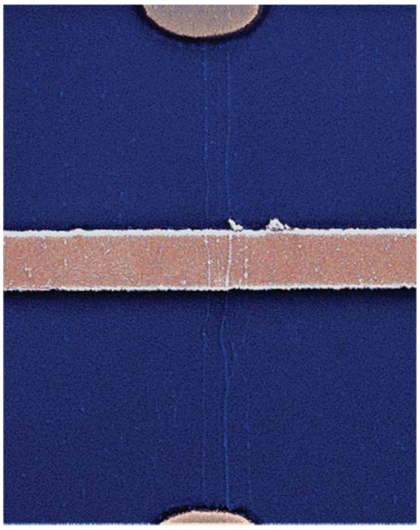
LEFT: RON DAHLQUIST/GETTY IMAGES; RIGHT: SIEMENS



ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

**9 NANOMETERS** Resolution of a new high-speed electron-beam lithography system constructed at MIT. About 25 nm was previously thought to be the limit for high-speed systems.

# update



**MEMORY THREAD:** Carbon nanotubes form a phase-change memory cell. *IMAGE: JIALE LIANG*

## Flash Challengers Work Well at Nanoscale

### Carbon nanotube electrodes test the limits of resistive RAM and phase-change memory

A TEAM OF scientists at Stanford University has used carbon nanotubes to create nanoscale versions of two next-generation memory technologies. The results help demonstrate that alternatives to flash memory will perform well even when scaled down to below 10 nanometers in size—a range where silicon memories won't function.

Flash memory is everywhere; it is the dominant storage technology in smartphones, tablets, and all other portable electronics. But the technology is approaching its density limit: With features smaller than about 16 nm, physical limitations—like charge leakage and damage from the high voltage needed to write information—will render the devices too error prone to be useful.

To assess the alternatives, IEEE Fellow H.-S. Philip Wong, a professor at Stanford, and his colleagues constructed tiny versions of two different types of memory that are being eyed as eventual successors to flash—resistive random-access memory (RRAM) and phase-change memory (PCM). The team presented its results in June at the 2011 Symposium on VLSI Technology, in Kyoto.

Like flash, both memories are nonvolatile, meaning they can retain information even when no power is being supplied to them. But the new memories promise to be far speedier and easier to miniaturize. They can also read and write smaller sets of bits than flash can, saving power in the process.

"One of the key questions is how far the technology can scale," Wong says. To investigate, his team set out to build memory cells about as small as is currently feasible, using 1.2-nm-wide nanotubes as electrodes. At that diameter, metal wires are very difficult to construct and suffer from high resistance as electrons scatter off grain boundaries and surfaces. Carbon nanotubes—rolled-up sheets of 1-atom-thick carbon—are better conductors.

To create the new memory structures, the team grew nanotubes on quartz and then applied a 100-nm-thick layer of gold that when lifted up pulls the nanotubes with it. The gold-nanotube layer is then placed on silicon, to which it adheres. Then the gold is etched away with chemicals to leave the nanotubes on the surface.

Wong's group used this transfer process to create a 6- by 6-nm RRAM cell consisting of two crosshatched layers of nanotubes separated by a layer of aluminum oxide. Information in the cell is changed by applying a voltage across the nanotubes that's high enough to create a conductive path through the normally resistive aluminum oxide. The team was able to create a fully operational memory cell that switches with less than 10 microamperes of current and about 10 volts. That's consistent with projections from other experiments, says Wong, and a sign that RRAM will scale well.

The team's PCM, which was constructed using a mixture of germanium, antimony, and tellurium, also proved promising. The researchers found they could switch an estimated $2.5\text{-nm}^2$ cell of the stuff from its conductive, crystalline phase to its resistive, amorphous phase with a current of just 1.4 μA—less than one-hundredth the current used in today's PCM cells.

The current that Wong's group used is consistent with the programming current recorded by Eric Pop and his colleagues at the University of Illinois at Urbana-Champaign, who reported tests of the first carbon-nanotube-based PCM in *Science* in April.

"I'm excited they were able to reproduce our results," Pop says. He reckons that with further miniaturization and a change in materials, engineers could cut the power consumption of PCM by another factor of 10.

Pop's team created its nanotube memory by laying phase-change material down in a gap along a horizontal carbon nanotube. Wong and his colleagues created a vertical version of this memory, in which phase-change material is sandwiched between bottom and top nanotube electrodes. This configuration is more compact than horizontal designs, Wong says, and will allow PCM cells to be scaled down much the way flash memory is today.

—RACHEL COURTLAND

*A version of this article appeared online as "Alternative Memories Get the Carbon Nanotube Test."*


# the big picture

## WORLD ON A STRING

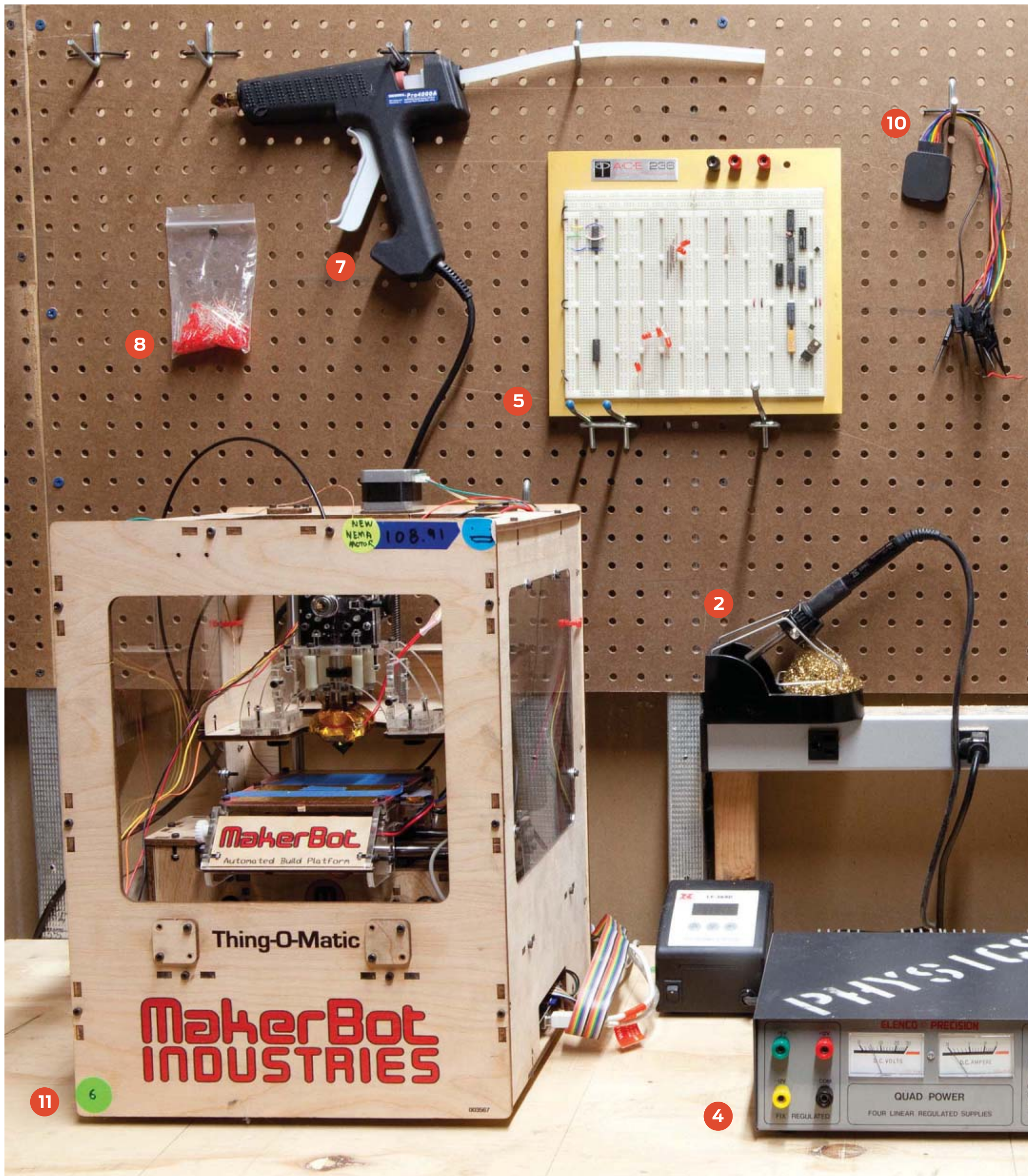
On 11 June, Mitsubishi Electric Corp. unveiled a 6-meter-diameter organic light-emitting diode (OLED) globe as part of the celebration of the 10th anniversary of the National Museum of Emerging Science and Innovation, in Tokyo. The Geo-Cosmos display comprises more than 10 000 OLED panels that together deliver an image containing 10 million pixels. The interactive globe can be programmed to show climate patterns, the locations of different species, and the impact of extreme events such as the March 2011 earthquake and tsunami that struck Japan.

*PHOTO: MIRAIKAN: NATIONAL MUSEUM OF EMERGING SCIENCE AND INNOVATION*

# hands on

## DIY Essentials

Does your do-it-yourself workbench have everything you need?



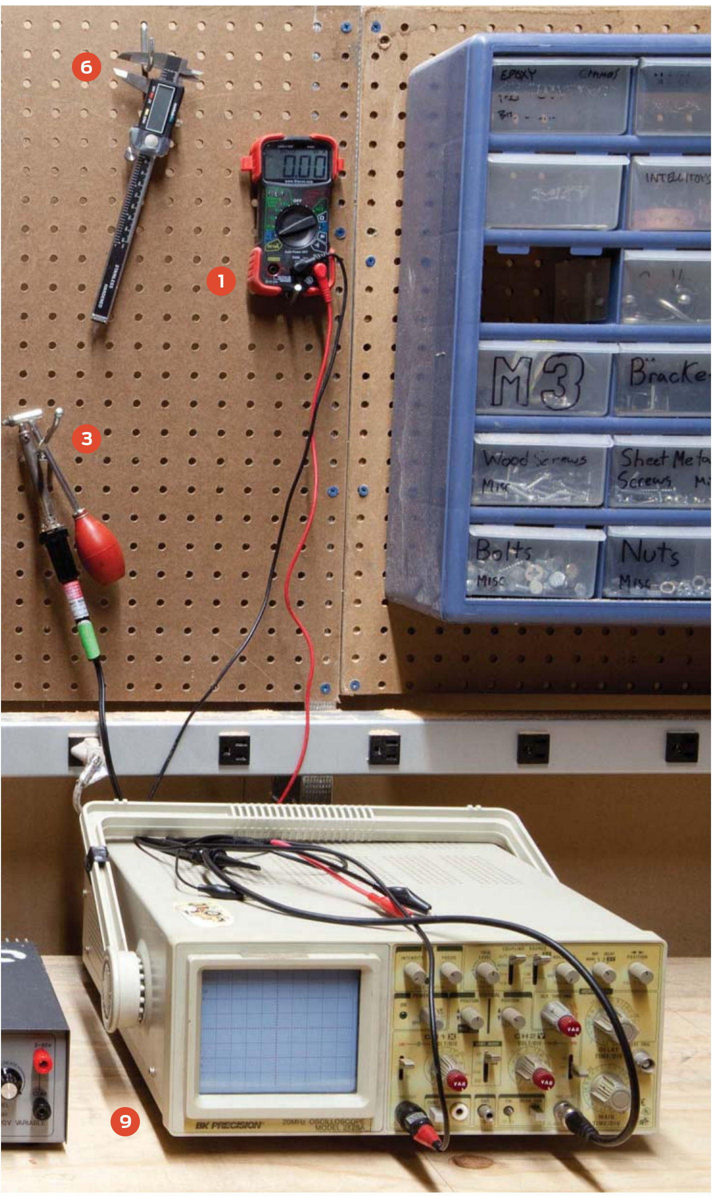

WHAT ARE the tools every hands-on projecteer needs? To answer that question, we went right to DIYers themselves, specifically the exhibitors at last fall's World Maker Faire NY event.

One tool everyone agreed on is a **MULTIMETER (1)**. It's surprising how much information you can glean from a simple resistance reading or by checking out the voltage drop across a series of LEDs. Basic analog meters start at around US $15, but consider getting one with a digital display and an audible continuity tester. When you're up to your arms inside a chassis probing a pair of contacts, you don't want to keep looking away just to see if you have continuity between two points. You'll also want a variety of ends for the probes, such as alligator clips and PC board lead hooks.

Next you'll want a **SOLDERING IRON (2)**. Some of the Maker Faire geeks didn't look for much more than the simple ones that cost less than $10, but others wanted the flexibility that a digitally controlled soldering station brings ($80; more for a name brand such as Weller). With advanced projects, you may need to vary the iron temperature depending on your components.

Sometimes, though, you just need a lot of heat, especially when soldering a large component or a thick wire. A conventional iron can't heat a large mass of metal quickly enough. Casey Haskell of Sparkfun Electronics likes to have a propane-powered pen iron for its portability, while others prefer a high-watt soldering gun.

Some of the Makers have moved beyond "through-hole" PC boards and now like to work with surface-mount devices. The "right" way to reflow solder for SMDs is using a purpose-made oven, but many a brave adventurer has gotten by with a toaster oven and some TLC. You can also use a hot-air gun or a hot-air pencil, which lets you do SMD one component at a time. Justin Huynh, who hacks remote-controlled cars with Arduinos, the popular DIY microcontrollers, uses




this technique as well as a variable-temperature Weller. "I've always used the Wellers," he says. "My friends who are engineers use them. They just work really well."

Along with an iron, you'll want to have a way to desolder, for those inevitable missteps. Some people like to use desoldering braid; others like **DESOLDERING IRONS (3)** with suction bulbs. I've used both, and I find the irons do a better job with less heating of the components.

Most of us start out using batteries or cannibalizing power adapters, but a good bench **POWER SUPPLY (4)** lets you control voltages precisely as well as measure and limit the amperage flowing through the circuit. You can get a reasonable single-voltage supply for $120 or so, such as the 18-volt, 3-ampere supply made by Extech Instruments. More advanced ones will offer multiple controllable voltages, useful when projects have more than one input voltage.

A bench supply goes well with a large **PROTOBOARD (5)**, one that supports multiple supply voltages and has lots of real estate to lay out chips. If you do a quick proof of concept on a protoboard first, you can save yourself a lot of grief when you try to set out a permanent version (or send it out to a printed-circuit-board fab).

Haskell notes that no good workbench should be without a few nonelectrical items as well, such as **CALIPERS (6)**. "I use them constantly," he says. They're especially critical when you start to lay out circuits in close quarters, such as inside an enclosure. Another go-to item is a good **HOT GLUE GUN (7)**. This is not to be confused with a craft glue gun, which uses low-temperature glue sticks. An industrial gun melts at a much higher temperature, and the material is nearly as hard as plastic when it cools. Haskell has another nontraditional tool in his bag of tricks. "A **BAG OF LEDS (8)** is really helpful," he says. "It's a good way to see if something is getting power."

So far, we've been talking about items that you can get for around $100. Of the Makers I spoke to who could afford one, the next tool they went for was an **OSCILLOSCOPE (9)**. A good one, such as a 40-megahertz Tektronix, can cost $950, and the prices rise quickly from there. Huynh says that his group had to pool their money to afford even a used one, a common strategy for hobbyists.

There's one other big-ticket item most makers yearn for. "We'd love to have a **LOGIC ANALYZER (10)** for working with chips," says Huynh, "but it's kind of pricey." A good one (better than the portable unit shown here) is invaluable, especially if you need to look at several seconds of history.

Haskell says that if money were no option, his next purchase would be either a desktop computer numerical control machine or a **3-D PRINTER (11)**. As it turns out, desktop CNC machines are coming down in price quickly; there are designs available for under $500 at this point. And 3-D printers are selling for less as well, some piggybacking on top of the new CNC platforms.

The nice thing about getting a workbench together is that you can do it gradually. That's why it's often worth spending a bit more to get the item you really want. There's nothing worse than having to buy something better six months down the road. Shop with care, consider used equipment, and before you know it, you'll be ready to tackle just about any project you can imagine.

—James Turner

RANDI SILBERMAN KLETT

# geek life

## WHO WAS SHAKESPEARE?

### The scholarly world isn't sure, but Wikipedia is

Wikipedia, today the seventh most popular site on the Web, is the go-to source for untold millions of users around the world. Yet, despite widely publicized worries that the self-edited and self-policed encyclopedia might subvert authority, the opposite concern has also emerged. Does Wikipedia, in other words, provide a viewpoint that's overly mainstream, giving short shrift to controversial, minority, or heretical ideas?

"All great truths," George Bernard Shaw famously wrote, "begin as blasphemies."

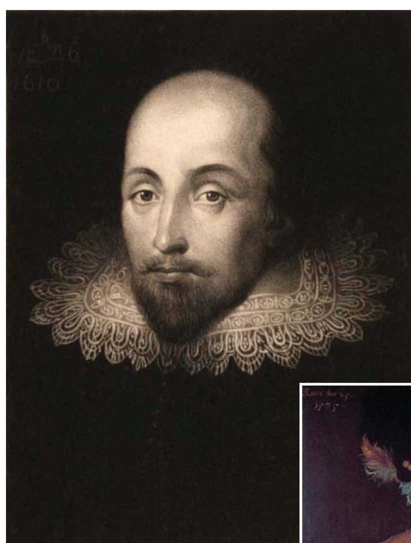
Consider the blasphemy that Shakespeare wasn't Shakespeare. According to this view, the Shakespeare veneer has been applied to plays and poems penned by one or more political insiders within the Elizabethan court. And William Shakespeare of Stratford-upon-Avon, they contend, was a mere collaborator or perhaps simply a front man.

This heresy has a century of scholarship behind it—its advocates include Walt Whitman, Sigmund Freud, Mark Twain, Henry James, Helen Keller, Derek Jacobi, and Malcolm X (as well as, in the interest of full disclosure, the present author). Yet a disproportionately large share of Wikipedia's "Shakespeare authorship question" entry, a page devoted to the controversy, has been written by proponents of the traditional Shakespeare-as-author thesis. This imbalance is the result of an 18-month battle that included mediation and arbitration hearings.

From 2006 through 2009, the SAQ—as its adherents abbreviate the entry—was largely coedited by one proponent of the mainstream—a.k.a. the "Stratfordian" point of view—and one proponent of the so-called Oxfordian theory, named for the leading alternative candidate, Edward de Vere, 17th Earl of Oxford.

"The page was relatively stable," says the top Oxfordian SAQ editor at the time, Stephen Moorer. "I had a good working relationship with the Stratfordian editor. The two of us kept the article going. We kept each other honest."

The balance shifted in December 2009. A regular disputant on related discussion boards—Tom Reedy, based in Denton, Texas—began editing the SAQ



Edward de Vere

**BARD IMBROGLIO:** Is Wikipedia slighting scholars who dispute Shakespeare's identity?

PHOTOS: TOP: UNIVERSAL HISTORY ARCHIVE/GETTY IMAGES; BOTTOM: TOM REEDY/WIKIPEDIA

in earnest. "It was very promotional," Reedy says. "It was obvious that [the Earl of] Oxford was being pushed."

In the ensuing months, Reedy and a pseudonymous Stratfordian editor named Nishidani rewrote much of the SAQ page and launched mediation and arbitration hearings against Moorer and another Oxfordian editor, who eventually was banned from Wikipedia altogether. Moorer was given a one-year "topic ban," prohibiting him from contributing to the SAQ or related entries.

The SAQ mediation, in particular, played out all too familiarly, according to John Broughton, author of *Wikipedia: The Missing Manual* (O'Reilly Media, 2008). "Mediation requires everyone to talk, and if it's going to be successful, it requires a good mediator," Broughton says.

In September 2010, the entry's Montagues and Capulets met on a designated mediation page, where they began hurling accusations and countercharges. But as Reedy posted in October, "The issues are still very much alive; but for some reason the moderator has gone AWOL." The mediation petered out the following month.

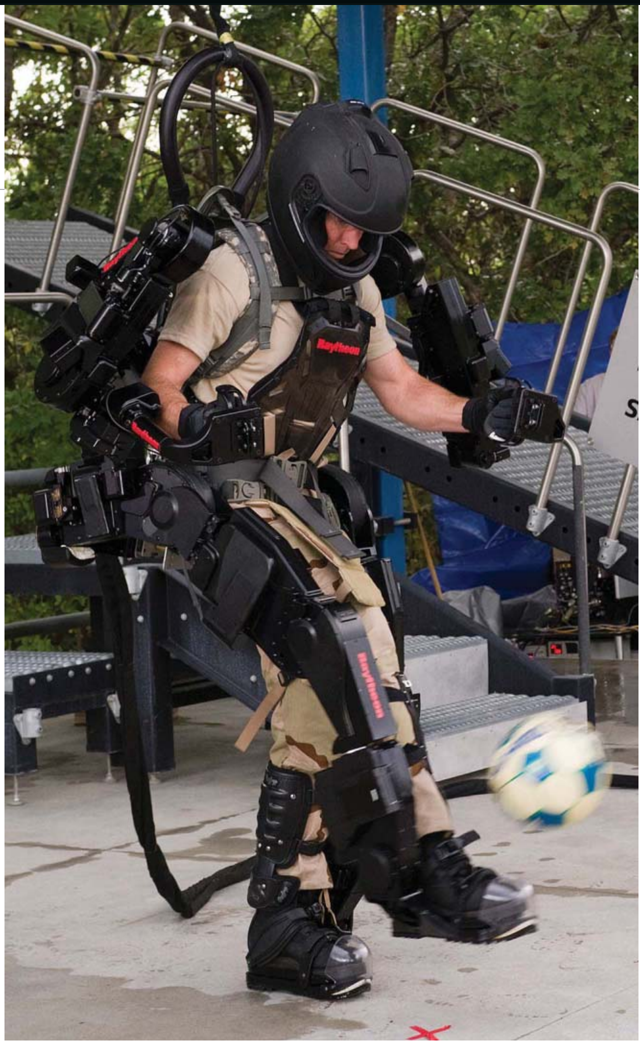
In April of this year, Wikipedia editors selected SAQ to be a "featured article," the site's highest rating, currently held by some 3000 articles. Yet the page that won the blue ribbon arguably has as much claim to evenhandedness as does an entry on Libya's history written by Muammar Gaddafi.

Even as the number of Wikipedia articles and readers rise, says Broughton, the number of Wikipedia participants is on the decline. And maintaining controversial pages is a particularly high-maintenance business.

In March, Ting Chen, a board member of the Wikimedia Foundation, Wikipedia's parent organization, pegged the decline in participation as "the most significant challenge currently facing our movement."

"Because it's one of these imperceptible things—less than a 1 percent decline in any given month—it's this very slow trickling away," Broughton says. "A lot of the holes are just not going to get filled."

—Mark Anderson



# RAIDING IRON MAN'S CLOSET

## A real-life Iron Man suit is almost ready to wear

RAYTHEON SARCOS'S second-generation exoskeleton robotics suit, XOS 2, which was named one of *Time* magazine's 50 Best Inventions last year, is now a mere five years away from production, its inventors say.

The wearable robotics suit augments the operator's strength by using a system of high-pressure hydraulics, sensors, actuators, and controllers to bear the weight of an object, while leaving its wearer agile enough to kick a soccer ball. It's also lighter, stronger, and more environmentally resistant, and it uses half the power of the company's first exoskeleton, XOS 1, which rolled out in 2008. The XOS 2 has been nicknamed the Iron Man suit in homage to the high-tech power suit in the comics and movies.

Since the 2010 introduction of the XOS 2, its engineers have continued to tweak the device, further increasing its power efficiency by cutting the suit's weight and redesigning the servo valves so that more hydraulic fluid can be forced through them without undue turbulence. They aim to reduce power consumption by more than 70 percent. That in turn will lead to smaller, lighter power sources and, ultimately, an increased payload.

**GOAAAAAAL!** The Iron Man suit allows its wearer enough agility to kick a soccer ball—and do push-ups. *PHOTOS: RAYTHEON*

The XOS 2 "doesn't feel any different if it's unloaded or you put 150 pounds [68 kilograms] on the back," says XOS 2 test engineer Rex Jameson. "I don't feel the strength, but I can pick up more. The big deal is that it takes a lot less power."

Raytheon Sarcos, a robotics development group within Raytheon's Integrated Defense Systems division, designed the suit to lighten a soldier's load and help the military reduce injuries. Military support personnel can find themselves each lifting as much as 7300 kg of supplies and armaments in a day, leading to considerable orthopedic damage.

"With a tethered power source, you could likely see [the exoskeleton deployed] within five years," says Fraser Smith, vice president of operations for Raytheon Sarcos, located in Salt Lake City. "For a suit that operates on its own power, it's probably more like a decade away."

Life has imitated art in more ways than just the suit's name. Eliot Brown—who illustrated the engineering mechanisms of the Iron Man suit for *The Official Handbook of the Marvel Universe* in 1983 and *The Iron Manual* in 1994—envisioned a suit in which computer-driven sensors were woven throughout instead of just in the joints.

The XOS 2 exoskeleton does indeed use a variety of sensors for determining force and position throughout the system. The sensors are connected via Ethernet to distributed computer processors in each joint, which prompt actuators (mechanical devices that turn energy into motion) to deliver up to 200 kg per square centimeter of force through high-pressure hydraulics.

"Basically, the person moves the way they normally would, and the exoskeleton keeps up," says Smith. "There is no external computation. Each joint has its own processing capability, and the joints communicate with each other." The revamped suit lets the wearer lift 50 lbs. (23 kg) with each arm at full horizontal extension.

Bob Layton, who cowrote and illustrated the comic's seminal "Demon in a Bottle" story line in 1979, adapted bionics and cybernetics concepts into his design of the Iron Man suits. "I was always more concerned about function, that it work as an extension of his mind and body," he says. "It makes sense that it would find its way into reality. All those engineers were probably comic geeks as kids."

Smith agrees. "This is a company full of geeks—and proud of it!" he laughs. "Most people here were very familiar with all those superheroes, although I'm partial to the early Iron Man comics with the guy dressed as a stove." —SUSAN KARLIN



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

# education

## MIT, YOU'RE NOT ALL THAT

### A new ranking system puts some lesser-known EE programs above the big-name schools

IN AN ARTICLE published by *The New Yorker* in February, Malcolm Gladwell rips apart college rankings for their subjective, and even arbitrary, criteria. "Who comes out on top," he concludes, "is really about who is doing the ranking."

Gladwell would surely be thrilled by the National Research Council's assessment of U.S. doctoral programs, published last September, which acknowledges the uncertainty of its results in the very way it presents them. Instead of ranking the programs No. 1, 2, 3, and so on, it merely puts each one within a range.

For example, the Massachusetts Institute of Technology's electrical and computer engineering program falls somewhere between 6th and 18th place among the 50 such programs the report considers. "What this tells people is that it's not an exact science and that there is a great deal of variability built into the process," says James Voytuk, a senior program officer at the NRC.

By contrast, MIT is consistently No. 1 in the rankings done by *U.S. News & World Report*, the target of much of Gladwell's ire. In many cases, the NRC's rankings depart not just from *U.S. News* but from conventional wisdom. MIT's electrical and computer engineering program isn't even in the top 5 of the NRC's rankings, while those of Princeton University and the University of California, Santa Barbara—which don't even make *U.S. News'* top 10—are.

The NRC's factors—there are 20 in all—include characteristics of the faculty (such as number of publications and citations), students (average GRE, percentage with full financial support), and the program in general (diversity, average time to degree, student activities offered). The data come from responses to questionnaires sent to faculty, administrators, and students about the 2005–2006 academic year. A typical ranking method would normalize these values, multiply them by a weight, and add them together to get a score. But the NRC's computation is much more sophisticated.

For one, it takes into account that the numbers fluctuate year to year. Its algorithm takes the mean and standard deviation, creates a Gaussian probability distribution, and then randomly generates a sample of 500 values from the distribution. This represents the data set that would result if the questionnaire were repeated 500 times.

It also uses two methods to weigh the 20 factors. One method involves directly asking faculty raters to assign numerical weights. The other is implicit, inferring the weights from the faculty evaluations of the programs. This gave two different sets of ranking ranges, which can be pretty different for the same school [see table, "Range Finder"].

Finally, the team also incorporates the uncertainty in the weights themselves by applying the "random-halves" technique. For each of the 20 factors, the algorithm takes a random subset of weights assigned by half the faculty raters and computes the average. It repeats this process 500 times.

In the end, each Ph.D. program has a set of 500 different rankings. The NRC discards the lowest and highest 5 percent and reports the remaining range. "What we said was maybe there's some outliers," Voytuk says. "That's the most honest way of doing it."

*U.S. News'* college rankings are clean, simple lists placing academic institutions in order. But, as Geoff Davis, a Google senior researcher and founder of PhDs.org points out, that's exactly their problem. "[They're] not very nuanced," he says. "If your needs are exactly the same as Robert Morse's, then by all means *U.S. News* is right." Morse is the man behind the *U.S. News* rankings.

Is having more data necessarily better? Looking at two sets of rankings with ranges does not make deciding on a grad school easy. But, says Davis, it's a tough decision.

The PhDs.org website uses the NRC data in its Grad School Guide. The guide lets students choose attributes that are important to them, assign weights to these factors, and create a customized list of rankings. "The key premise is there's no best program; there's a best program for you," he says. "It's kind of like getting married. There's no best spouse; there's just a best spouse for you."

—PRACHI PATEL

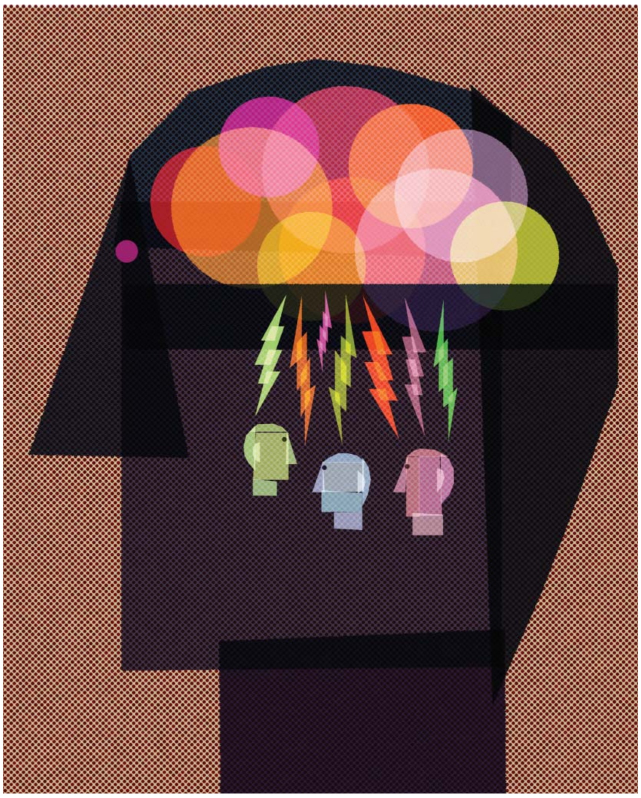
| DOCTORAL PROGRAMS IN ELECTRICAL AND COMPUTER ENGINEERING | *U.S. NEWS & WORLD REPORT* | NATIONAL RESOURCE COUNCIL (DIRECT/INDIRECT)* |
|---|---|---|
| Massachusetts Institute of Technology | 1 | 7–15/6–18 |
| Stanford University | 2 | 1/1–3 |
| University of California, Berkeley | 3 | 6–15/7–26 |
| Georgia Institute of Technology | 4 | 2–7/ 8–30 |
| University of Illinois at Urbana-Champaign | 5 | 3–7/4–13 |

**RANGE FINDER:** A new National Research Council assessment of U.S. doctoral programs in electrical and computer engineering not only replaces ranks with ranges, it downgrades some traditional favorites.

** For the direct ranking, faculty raters assign numerical weights directly. In the indirect method, rankings were derived from faculty evaluations of a graduate program's characteristics.*
*NOTE:* U.S. News *rankings were for the 2010–11 academic year. The NRC data concern 2005–06.*

# technically speaking

BY PAUL McFEDRIES



GREG MABLY

## The Selfish Meme

A new kind of replicator has recently emerged on this very planet. It is staring us in the face. It is still in its infancy, still drifting clumsily about in its primeval soup, but already it is achieving evolutionary change at a rate that leaves the old gene panting far behind.
—Richard Dawkins, *The Selfish Gene*

AT THE end of his 1976 book *The Selfish Gene*, geneticist Richard Dawkins proposed the idea of the meme, which he described as "a unit of cultural transmission" analogous to the gene. The meme idea was so powerful that it quickly became a meme itself as it spread from mind to mind with the peculiar inevitability that seems to characterize all memes. (Indeed, the philosopher Daniel Dennett has described the meme as "an information-packet with attitude.") For our purposes here, the *meme* meme has spawned a rather impressive lexicon of terms, many of which come from the field of **memetics**, the study of memes. (I'm indebted to **memeticist** Tim Tyler and the good folks at the website Know Your Meme for many of these terms.)

Although Dawkins's analogue for the meme was the gene, current meme lingo is heavily weighted toward epidemiology. Thus, synonyms include **ideavirus**, **virus of the mind**, and **thought contagion**. Similarly, the medium that carries a meme is called a **vector**, the successful insertion of a meme into a person's brain is called an **infection**, and the infected person is a **host**. A readily contagious meme is said to have **sneezability**. An **active meme** affects the behavior of its host, as opposed to an **inactive** or **latent meme**. A host that reacts negatively—for example, by advocating censorship of the meme—has a **meme allergy**. If the meme causes self-destructive behavior in the host—as, for example, a meme about martyrdom might—the host is called a **memoid**, by analogy with *android*. When a prior infection by one meme prevents a host from being affected by another, the original meme is called an **immuno-meme**.

A **grassroots meme** begins with, and is for the most part propagated by, ordinary users rather than, say, a corporation. If some big-time marketer fakes a grassroots meme, then you have an **astroturf meme**. A similar idea is the forced meme, which is someone's deliberate (and usually unsuccessful) attempt to create a meme.

Memes that evolve alongside a larger meme are called **comemes** or, since the two memes have a kind of symbiotic relationship, **symmemes**. More specifically, a **bait meme** offers some benefit to the host if it adopts the main meme. (For example, if the main meme is Christianity, the bait meme might be an eternal afterlife.) Many main memes also come with a **hook meme** that, after the host has taken the bait meme, causes the host to replicate the main meme. (In the Christianity example, a hook meme would be the idea of spreading the gospel.) When a main meme is surrounded by one or more comemes, the resulting constellation of ideas is a **meme complex** or a **memeplex**.

Forums that are prolific generators of memes are called **memetic hubs**, and sites that are particularly adept at spreading existing memes are called **amplifiers**. These sites often specialize in certain meme types, including the **phrasal template** (such as the snowclones I featured in a 2008 column), the **image macro** (a picture with varying text, such as LOLcat images), and the **subvertisement** (a **meme hack** that modifies an ad to subvert its original message). On the negative side is the **zombie lie**, a false statement that keeps getting repeated no matter how often it has been refuted.

Richard Dawkins became famous in the 1970s for his concept of the selfish gene, and he has become infamous in recent years for his unyielding atheism. But I predict that Dawkins will be known, a hundred years hence, not for these contributions to science and culture but for the concept of the meme. Feel free to spread that idea around. ❏

# AUTONOMOUS ROBOTS IN THE FOG OF WAR

**NETWORKS OF INTELLIGENT ROBOTS WILL SOMEDAY TRANSFORM WARFARE—BUT SIGNIFICANT HURDLES REMAIN**

**BY LORA G. WEISS**

**TWO SMALL PLANES FLY LOW OVER A VILLAGE,** methodically scanning the streets below. Within minutes, they spot their target near the edge of town. With no way to navigate through the streets, they radio for help. Soon after, a metallic blue SUV begins moving cautiously but purposefully along the dirt roads leading to town, seeking out the target's GPS coordinates. Meanwhile, the planes continue to circle overhead, gathering updated information about the target and its surroundings. In less than half an hour after the planes take to the sky, the SUV has zeroed in on its quarry. Mission accomplished.

Last fall, my research team fielded these vehicles at Fort Benning, Ga., during the U.S. Army's Robotics Rodeo. That's right, the two quarter-scale Piper Cub aircraft and the Porsche Cayenne operated without any humans at the controls. Instead, each robot had an onboard computer running collaborative software that transformed the three machines into an autonomous, interoperable system.

The demonstration may sound simple—the target was just a tarp staked to the ground—but had this been the streets of Kabul or Baghdad, where any pile of debris can conceal a deadly improvised explosive device, such autonomous tracking robots in the future could help keep soldiers out of harm's way. Indeed, military leaders have increasingly embraced the use of unmanned aerial vehicles (UAVs) and other robotic systems over the past decade, to handle the "three D's": the dull, dirty, and dangerous tasks of war. Back in 2000, the U.S. Department of Defense (DOD) had fewer than 50 UAVs in its inventory; by early 2010, it had more than 7000. In 2009, the U.S. Air Force started training more pilots to operate unmanned systems than to fly fighters and bombers. And according to market research firm ABI Research, 65 countries now use military robots or are in the process of acquiring them.

The ranks of battlefield robots will only grow: The U.S. Congress has mandated that by the year 2015, one-third of ground combat vehicles will be unmanned, and the DOD is now developing a multitude of unmanned systems that it intends to rapidly field. Meanwhile, thousands of robotics researchers worldwide are making impressive gains in networking robots and boosting the sophistication and autonomy of these systems.

Despite the advances in both their performance and safety, these robots are still far from perfect, and they routinely operate in situations for which they may not have been designed and in which their responses cannot always be anticipated. Some of the DOD's most advanced UAVs carry dozens of sensors, including high-resolution night-vision cameras, 3-D imagers, and acoustic arrays. Yet most cannot distinguish a sleeping dog from a bush, even at high noon. Humans are still needed to operate the vehicles, interpret the data, and coordinate tasks among multiple systems. If we are ever to see fully autonomous robots enter

PREVIOUS SPREAD: PHOTO-ILLUSTRATION: NOEMOTION

### PREDATOR

DEVELOPER General Atomics

DESCRIPTION Unmanned aerial vehicle (UAV) for surveillance and, when equipped with Hellfire missiles, for combat. Can be remotely piloted or programmed to follow GPS waypoints.

STATUS First deployed in 1995. Since 2001, primarily used for combat. Currently, 360 operated by U.S. military in Afghanistan, Iraq, Pakistan, and elsewhere. Also used by Italian Air Force and the United Kingdom's Royal Air Force.

### TALON

DEVELOPER Foster-Miller/Qinetiq Group

DESCRIPTION 52-kilogram remotely operated unmanned ground vehicle that can be equipped for various missions, including infrared and night-vision cameras for reconnaissance, manipulator arm for improvised explosive device (IED) disposal, and rifle or grenade launcher for combat.

STATUS Deployed by U.S. military in Bosnia, Iraq, Afghanistan, and elsewhere.

### BLUEFIN HAUV

DEVELOPER Bluefin Robotics Corp./Battelle Memorial Institute

DESCRIPTION 79-kg unmanned underwater vehicle for ship hull inspection using high-resolution sonar. When equipped with a manipulator arm and camera, it can also do IED detection and disposal. Conducts surveys autonomously or can be remotely operated via fiber-optic tether.

STATUS U.S. Navy awarded Bluefin US $30 million production contract in March 2011.

FROM LEFT: ETHAN MILLER/GETTY IMAGES; QINETIQ; BLUEFIN ROBOTICS



ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

the battlefield—those capable of planning and carrying out missions and learning from their experiences—several key technological advances are needed, including improved sensing, more agile testing, and seamless interoperability. Even then, a basic question will remain: How can we equip these robots to make critical decisions on their own?

A REPORTER ON THE PHONE asks me what will happen when robots become so smart that they can clone themselves. He seems to assume it's a given: Robots will someday be agile enough to create exact copies of their mechanical bodies and of the software code comprising their "brains." All he wants to know from me is when—not if—this great day will arrive. I suggest that he not hold his breath.

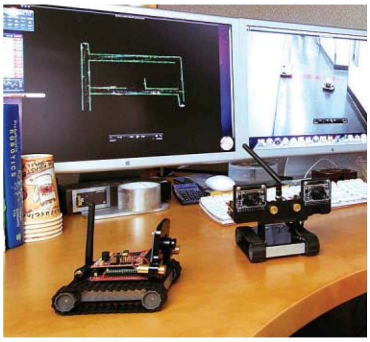
As a researcher at the Georgia Tech Research Institute and a board member of the world's largest association for unmanned systems—the Association for Unmanned Vehicle Systems International—I've been working with robots for more than two decades, starting with underwater vehicles, then moving to air and ground vehicles, and most recently addressing collaborations among robots like those we demonstrated at the Robotics Rodeo. I can attest that while robots are definitely getting smarter, it is no easy task to make them so smart that they need no adult supervision. And call me a skeptic, but I doubt they'll be cloning themselves anytime soon.

That said, I'm amazed at the pace of progress in the field. With thousands of researchers now engaged in advancing the intelligence and autonomy of unmanned systems, new breakthroughs are announced seemingly every week. Both the variety and the number of unmanned systems now deployed are breathtaking. UAVs run the gamut from the 1-metric-ton MQ-1 Predator drone made by General Atomics to AeroVironment's tiny 430-gram Wasp micro air vehicle. There are unmanned ground vehicles that roll on treads like tanks, walk like dogs, and slither like snakes. Unmanned maritime vehicles include submarine-like vessels that can cruise underwater for kilometers and boatlike craft that patrol for pirates, smugglers, and other criminal types.

But none of these systems are fully autonomous. The RQ-4 Global Hawk UAV, made by Northrop Grumman, is guided by satellite waypoint navigation, yet it still requires a human pilot sitting in a remote ground station, plus others to operate the drone's sensors and analyze the data being sent back. iRobot's PackBot tactical robot is teleoperated by means of a video-game-style controller, complete with joystick. Even the driverless vehicles that participated in the Defense Advanced Research Projects Agency's Grand Challenge competitions in 2004, 2005, and 2007 weren't entirely autonomous, as the courses they had to negotiate were tightly controlled.

So why haven't we seen a fully autonomous robot that can sense for itself, decide for itself, and seamlessly interact with people and other machines? Unmanned systems still fall short in three key areas: sensing, testing, and interoperability. Although the most advanced robots these days may gather data from an expansive array of cameras, microphones, and other sensors, they lack the ability to process all that information in real time and then intelligently act on the results. Likewise, testing poses a problem, because there is no accepted way to subject an autonomous system to every conceivable situation it might encounter in the real world. And interoperability becomes an issue when robots of different types must interact; even more difficult is getting manned and unmanned systems to interact.

TO APPRECIATE the enormous challenge of robotic sensing, consider this factoid, reported last year in *The Economist*: "During 2009, American drone aircraft…sent back 24 years' worth of

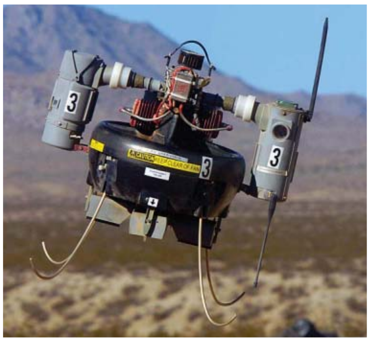


### MAPPING SWARMBOTS

DEVELOPERS Georgia Tech, University of Pennsylvania, and Jet Propulsion Laboratory

DESCRIPTION Collaborative robots that can autonomously map an entire building for first-responder and military applications. Each palm-sized robot is equipped with a video camera for identifying doorways and windows and a laser scanner for measuring walls.

STATUS Developed under U.S. Army Research Lab's five-year, $38 million Micro Autonomous Systems and Technology program. Mapping experiment conducted in 2010; next iteration to include small UAVs.



### T-HAWK

DEVELOPER Honeywell International

DESCRIPTION Vertical takeoff and landing 8-kg micro air vehicle equipped with color and infrared video cameras for intelligence, surveillance, and reconnaissance. Can hover and observe for up to 50 minutes at altitudes of up to 3000 meters.

STATUS Deployed in Iraq starting in 2007 for roadside bomb detection. Surveyed damage at Fukushima nuclear power plant following March 2011 earthquake and tsunami in northeastern Japan.

### X-47B

DEVELOPER Northrop Grumman Corp.

DESCRIPTION U.S. Navy's stealth unmanned combat aerial vehicle designed for takeoff and landing on an aircraft carrier. Has a range of 3380 kilometers and can carry up to 2000 kg of ordnance in two weapons bays. Originated as a project of the Defense Advanced Research Projects Agency.

STATUS First test flight February 2011. Scheduled deployment by 2018.

FROM LEFT: GEORGIA INSTITUTE OF TECHNOLOGY; HONEYWELL; NORTHROP GRUMMAN video footage. New models…will provide ten times as many data streams…and those in 2011 will produce 30 times as many." It's statistics such as those that once prompted colleagues of mine to print up lanyards that read "It's the Sensor, Stupid."

But a robot is more than just a platform of sensors. Let's say an unmanned jeep is traveling down a city street. Its cameras may detect a parked car along the curb, an open manhole in the middle of the road, and a knot of school kids crossing at the intersection. But unless the jeep can correctly classify the car as a car, the manhole as a manhole, and the children as children, it won't have sufficient information to avoid those obstacles.

So the sensing problem in robotics extends well beyond just designing sophisticated new sensors. An autonomous robot needs to be able to automatically process the data from those sensors, extract relevant information from those data, and then make decisions in real time based on that information and on quickly as it could. It should not take five people to fly one UAV; one soldier should be able to fly five UAVs.

On the other hand, because military robots typically operate in geopolitically sensitive environments, some added caution is certainly warranted. What happens, for example, if a faulty sensor feeds a UAV erroneous data, causing it to cross a border without authorization? What if it mistakenly decides that a "friendly" is a target and then fires on it? If a fully autonomous, unmanned system were to make such a grave mistake, it could compromise the safety of other manned and unmanned systems and exacerbate the political situation.

THE PREDATOR UAV, developed in the 1990s, went from concept to deployment in less than 30 months, which is extremely fast by military procurement standards.

Little wonder, then, that the UAV exhibited quite a few kinks upon entering the field. Among other things, it often

## ROBOTS IN COMBAT

**Books have been written** about the feasibility and ethics of weaponizing robots, and it's not my intent to explore that topic in any great detail here. The fact is, weaponized robots—missile-launching unmanned combat air vehicles, rifle-toting unmanned combat ground vehicles, and mine-deploying unmanned combat underwater vehicles—are already a reality.

At present the decision of whether these robots attack is still left to humans. But as robots gain more autonomy, will we or won't we allow them to decide to fire weapons on their own? The U.S. Defense Department continues to mull the issue. In 2007, for instance, it released a report called *Unmanned Systems Safety Guide for DOD Acquisition*, which includes a section on designing weaponized unmanned systems. It lays out a number of ethical, legal, and technical areas of concern that any designer of armed autonomous robots should be prepared to address. These include the inadvertent firing of weapons, erroneous target discrimination, and the possibility of the enemy taking control of the unmanned system.

John Canning of the Naval Surface Warfare Center Dahlgren Division, in Virginia, has pointed out that deploying weaponized robots while maintaining a human operator to do the actual firing is costly. He's put forth several concepts of operation that might allow autonomous armed robots to coexist on the battlefield with other manned and unmanned systems. One of Canning's key concepts is to "let machines target other machines." That is, design armed unmanned systems so that they can automatically identify, target, and neutralize or destroy the weapons used by adversaries, but not the people using the weapons.

In those instances when it becomes necessary to target humans, Canning proposes that an armed unmanned system not be allowed to act autonomously but rather be remotely controlled by humans. The machine, he suggests, should be designed with "dial-a-level" autonomy so that it can switch among operational modes according to its environment and other circumstances. It would also be equipped with both nonlethal and lethal weapons, the former for convincing the enemy to abandon its arms and the latter for actually destroying those weapons.

Ronald C. Arkin, director of the Mobile Robot Laboratory at Georgia Tech, has been looking at ways to imbue robots with a sense of "ethics" and even an artificial "conscience" so that they adhere to international rules of warfare. That should make it possible, he believes, for autonomous robots to conduct themselves on the battlefield at least as well as humans—and probably better. *—L.G.W.*

information it has gathered in the past. The goal is to achieve what researchers call situational understanding.

And with no humans in the loop to help interpret the data, reason about the data, and decide how to respond, situational understanding gets even trickier. Using current technology, no robot has all the onboard sensors needed to precisely decipher its environment. What's more, decisions have to be made based on uncertainties and incomplete or conflicting information. If a robo-sentry armed with a semiautomatic rifle detects someone running from a store, how can it know whether that person has just robbed the store or is simply sprinting to catch a bus? Does it fire its weapon based on what it thinks is happening?

Humans, too, may struggle to read such a situation, but perhaps unsurprisingly, society holds robots to a higher standard and has a lower tolerance for their errors. This bias may create a reluctance to take the leap in designing robots for full autonomy and so may prevent the technology from moving ahead as failed when flying in bad weather, it was troublesome to operate and maintain, and its infrared and daylight cameras had great difficulty discerning targets. But because commanders needed the drone quickly, they were willing to accept these imperfections, with the expectation that future upgrades would iron out the kinks. They didn't have time to wait until the drone had been thoroughly field-tested.

But how do you test a fully autonomous system? With robots that are remotely operated or that navigate via GPS waypoints, the vehicle's actions are known in advance. Should it deviate from its instructions, a human operator can issue an emergency shutdown command.

However, if the vehicle is making its own decisions, its behavior can't be predicted. Nor will it always be clear whether the machine is behaving appropriately and safely. Countless factors can affect the outcome of a given test: the robot's cognitive information processing, external stimuli, variations in

DON FARRALL/GETTY IMAGES



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

the operational environment, hardware and software failures, false stimuli, and any new and unexpected situation a robot might encounter. New testing methods are therefore needed that provide insight and introspection into why a robot makes the decisions it makes.

Gaining such insight into a machine is akin to performing a functional MRI on a human brain. By watching which areas of the brain experience greater blood flow and neuronal activity in certain situations, neuroscientists gain a better understanding of how the brain operates. For a robot, the equivalent would be to conduct software simulations to tap the "brain" of the machine. Subjecting the robot to certain conditions, we could then watch what kinds of data its sensors collect, how it processes and analyzes those data, and how it uses the data to arrive at a decision.

Another illuminating form of testing that is often skipped in the rush to deploy today's military robots involves simply playing with the machines on an experimental "playground." The playground has well-defined boundaries and safety constraints that allow humans as well as other robots to interact with the test robot and observe its behavior. Here, it's less important to know the details of the sensor data and the exact sequence of decisions that the machine is making; what emerges on the playground is whether or not the robot's behavior is acceptably safe and appropriate.

Moving to smarter and more autonomous systems will place an even greater burden on human evaluators and their ability to parse the outcomes of all this testing. But they'll never be able to assess all possible outcomes, because this would involve an infinite number of possibilities. Clearly, we need a new way of testing autonomous systems that is statistically meaningful and also inspires confidence in the results. And of course, for us to feel confident that we understand the machine's behavior and trust its decision making, such tests will need to be completed before the autonomous robot is deployed.

A SWARM OF SMALL ROBOTS scatters across the floor of an abandoned warehouse. Each tread-wheeled bot, looking like a tiny tank with a mastlike antenna sticking out of its top, investigates the floor space around it using a video camera to identify windows and doors and a laser scanner to measure distances. Employing a technique called SLAM (for "simultaneous localization and mapping"), it creates a map of its surroundings, keeping track of its own position within the map. When it meets up with another robot, the two exchange maps and then head off to explore uncharted territory, eventually creating a detailed map of the entire floor.

These ingenious mapping robots, designed by researchers through the U.S. Army–funded Micro Autonomous Systems and Technology program, represent the cutting edge of robot autonomy. In future iterations, their designers plan to equip the machines with wall-penetrating radar and infrared sensors, as well as a flexible "whisker" to sense proximity to obstacles. Clever as they are, though, these robots lack a key capability that all future robots will need: They cannot easily interact with other kinds of robots.

Now consider the U.S. Navy's Littoral Combat Ship. Rather than having a fixed architecture, it will have swappable "mission modules" that include vertical takeoff unmanned aerial vehicles, unmanned underwater vehicles, and unmanned surface vehicles. All these robotic systems will have to operate in concert with each other as well as with manned systems, to support intelligence, surveillance, and reconnaissance missions, oceanographic surveys, mine warfare, port security, and so on.

Achieving this interoperability will be no small feat. While significant progress has been made on automating a single robot as well as a team of identical robots, we are not yet at the point where an unmanned system built for the Army by one contractor can seamlessly interact with another robotic system built for the Navy by another contractor. Lack of interoperability isn't exclusively a robotics problem, of course. For decades, developers of military systems of all kinds have tried and often failed to standardize their designs to allow machines of different pedigrees to exchange data. But as different branches of the military continue to add to the ranks of their battlefield robots, the enormous challenge of interoperability among these disparate systems only grows.

A particular difficulty is that most automation and control approaches, especially those used for collaborating, assume that all the unmanned systems have the same level of autonomy and the same software architecture. In practice, that is almost never the case, unless the robots have been designed from scratch to work together. Clearly, new approaches are needed so that you can introduce an unknown, autonomous system without having to reconfigure the entire suite of robots.

Interoperability between manned and unmanned systems is even more challenging. The ultimate goal is to have autonomous systems collaborate with humans as equal partners on a team, instead of simply following commands issued by their operators. For that to happen, though, the robots will need to understand human language and intent, and they will need to learn to communicate in a way that is natural for humans.

Interoperability also requires standards, procedures, and architectures that enable effective integration. Today, for instance, unmanned ground and maritime systems use a messaging standard called the Joint Architecture for Unmanned Systems (JAUS). The messaging standard for unmanned air systems, meanwhile, is STANAG-4586, a NATO-mandated format. Within their respective domains, both of these serve their purpose.

But when a UAV needs to communicate with an unmanned ground vehicle, should it use JAUS or STANAG-4586 or something else entirely? The most promising effort in this arena is the JAUS Tool Set, an open, standards-based unmanned vehicle messaging suite that is in beta testing. Using the tool set seems to improve interactions among unmanned vehicles. In the future, the tool set should allow the two message formats to be merged. Ultimately, that should accelerate the deployment of compatible and interoperable unmanned systems.

As robotic systems become more autonomous, they will also need the ability to consider the advice, guidance, and opinions of human users. That is, humans won't be dictating behavior or issuing hard directives, but they should still be able to influence the robot's planning and decision making. Integrating such information, including its vagaries, nuances, and uncertainties, will be a challenge for any autonomous system as its intelligence increases. But attaining these capabilities is within our reach. Of that, I am not skeptical. ❑

**POST YOUR COMMENTS** *online at* http://spectrum.ieee.org/robots0811



ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

# MAGNET MAKEOVER

## RARE EARTH MAGNETS ARE ALREADY EXCEEDINGLY STRONG. NANOTECHNOLOGY COULD SOON DOUBLE THEIR POWERS OF ATTRACTION

BY GEORGE HADJIPANAYIS & ALEXANDER GABAY

ISTOCKPHOTO

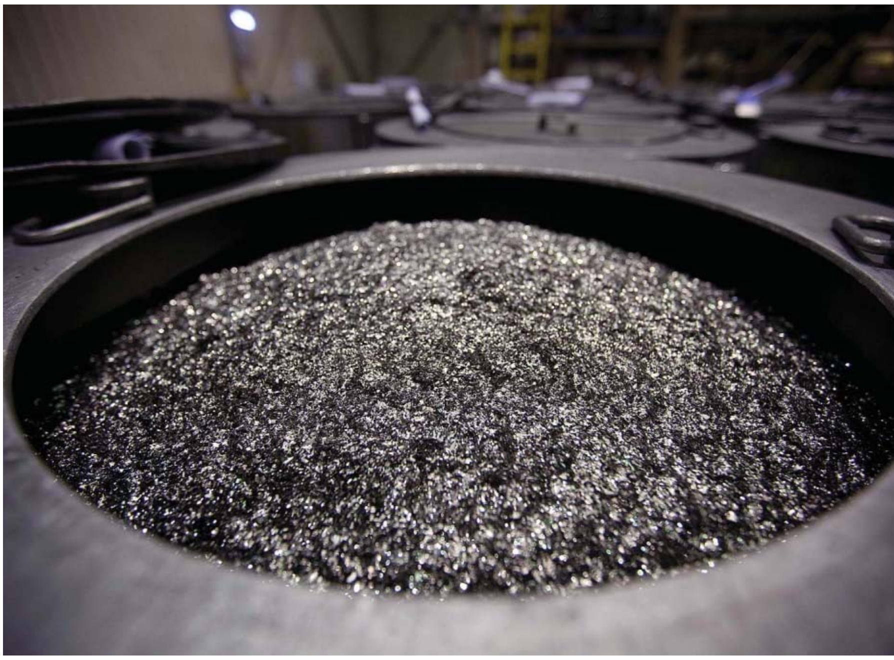
**IN ANCIENT TIMES,** they were considered magical objects with supernatural powers. These days, we just stick them on our refrigerators. Yet those little magnets deserve our admiration more than ever.

Take laptop computers, with their slim hard drives. It became possible to manufacture the motors for those drives only after the development of especially powerful permanent magnets in the early 1980s. Such muscular magnets are now found in many other places as well—various household appliances, cellphones, and the small electric motors that operate accessories in our cars, to name a few. They are also critical in the brawny electric motors that propel hybrid vehicles and in the generators attached to many wind turbines. So they can help both to reduce energy consumption and produce green electric power.

Because the magnets themselves are hidden away, many of us tend to take them for granted. We shouldn't, especially not now. The manufacture of most high-performance magnets requires neodymium, a rare earth element that's in short supply. Almost all of the world's production comes from China, which has increasingly restricted exports to ensure that it has enough to satisfy its own needs. So the price of neodymium has been skyrocketing. If the trend continues, pretty soon we'll have a real crisis on our hands.

MINING COMPANIES are scrambling to develop other sources of neodymium ore, a process that can take a decade or more. But what if you could make magnets even more powerful than today's best using less neodymium, or maybe even using an element that's a lot more plentiful? Not only would that ease concerns about shortages, it would result in smaller and more efficient motors and generators.

In the past, when researchers went looking for ways to make better permanent magnets, they were pretty much restricted to combining various mostly metallic elements into a single magnetic alloy. Now some of us are pushing an entirely different approach: We hope to construct ultrastrong magnets using two different alloys combined at the nanometer scale. That's not an easy thing to do, but if researchers can overcome the remaining technical obstacles, such "nanocomposite magnets" could allay worries over the dwindling supply of neodymium. And such magnets could make motors, generators, loudspeakers, and the like more compact and efficient, which is a worthwhile goal in itself.



How do you go about making a permanent magnet? Magnetism starts with individual atoms, so let's begin there. Only some kinds of atoms are magnetic, having what physicists call a magnetic moment, meaning that the atom acts like a tiny bar magnet. You'll definitely want to enlist atoms that are strongly magnetic in your creation. Iron, nickel, and cobalt all qualify. The rare earth elements neodymium and samarium are even better. The way those atoms are arranged is also important: You'll need a material in which these atomic bar magnets naturally tend to line up. This happens in many crystalline substances because of something physicists call exchange forces, a quantum-mechanical effect that operates over just a few nanometers, coaxing the magnetic moments of nearby atoms to align.

In many materials, that alignment is easily disturbed, destroying the magnetization. To avoid that, it's best to pick a material whose crystal lattice has just one direction that the magnetization can easily align with—think of the grain in a piece of lumber. Physicists call this, naturally enough, the easy direction of magnetization. The atomic bar magnets prefer that orientation to any other, which makes for a stable, or as physicists sometimes call it, a "hard" magnet.

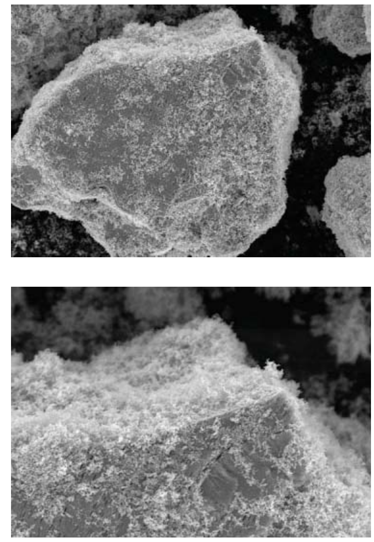
But there's a complication. Most crystalline materials actually consist of many tiny crystallites packed together, so you'll likely be dealing with a bunch of little crystals, each with its own easy direction of magnetization. To get all their magnetic moments working in unison, you have to take pains to orient the easy directions of all the crystallites in parallel. Even if you're successful, the thing you create probably won't be uniformly magnetized. Instead, it will spontaneously divide itself into what are known as magnetic domains. The magnetic moments inside each domain will lie along the easy direction, but left to themselves, adjacent domains will point in opposite directions, canceling each other out.

This problem can be fixed by applying a strong magnetic field with a powerful electromagnet. As you turn up the current and apply a stronger and stronger magnetic field, the domains that are better aligned with that field will grow and eventually consume the other, less fortunate kind of domains. Once all the domains become fully aligned, the material reaches what physicists call the saturation magnetization. A good permanent magnet will keep most of that magnetization after the applied field is removed.

To find out how magnetically hard something is, physicists measure the strength of the coercive field, the reverse-directed magnetic field that's required to erase the material's magnetization completely. The greater the coercive field, the better, because magnets always work in a hostile magnetic environment, one that tends to demagnetize them. The rub here is that materials with strong coercive fields don't usually have much magnetic oomph—which is to say that at best, they exhibit modest saturation magnetizations.

Measuring the saturation magnetization and coercive field of a magnet tells you a lot about it. But what you'll really want to know after you've cobbled together a new magnet is a quantity called the maximum energy product. You can think of it as a measure of energy stored in 1 cubic centimeter of the magnetic material, although it's not stored in the sense that energy is stored in a battery or a capacitor—you can't just drain it off at will. And you wouldn't want to: The magnetic energy in 1 cubic centimeter of even a state-of-the-art magnet is surprisingly small—it could power a typical Christmas-tree bulb for only a fraction of a second. Yet the unique way this energy is retained within the material makes it truly indispensable, because it allows the thing to be permanently magnetic.

RARE COMMODITY: The raw materials for high-performance neodymium-iron-boron magnets are displayed at Chinese factories in Bautou [top] and Tianjin [middle and bottom].
PHOTOS: FROM TOP, NELSON CHING/BLOOMBERG/GETTY IMAGES; DOUG KANTER/BLOOMBERG/GETTY IMAGES (2)



**WITH SPRINKLES:** A 20-micrometer magnetic core [top] is coated with iron nanoparticles, as can be clearly seen in the enlargement [bottom].
PHOTOS: TOP, COURTESY OF M. MARINESCU/JOURNAL OF APPLIED PHYSICS/AMERICAN INSTITUTE OF PHYSICS; BOTTOM, ALEXANDER GABAY

The maximum energy product of a magnet is often measured in units of millions of gauss oersteds, or MGOe. Its value determines the volume that a magnet must have to generate a magnetic field of a certain strength. The higher the maximum energy product, the smaller the magnet needed for a given purpose, whether it's spinning a motor, levitating a magnetic bearing, or sticking a calendar on the door of your fridge.

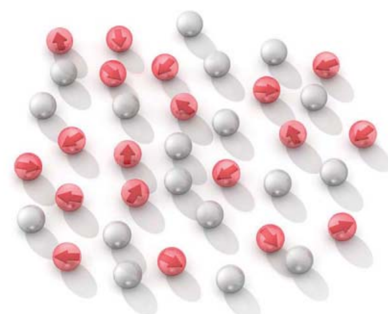
Physicists and materials scientists have invested enormous effort trying to find mixtures of elements that produce both high saturation magnetizations and strong coercive fields. The best results have come from using various combinations of samarium and cobalt or of neodymium, iron, and boron. Samarium-cobalt magnets have better temperature stability, but they are expensive, and their maximum energy products are only some 20 to 30 MGOe. Neodymium-containing magnets often have energy products of 40 to 50 MGOe and are less costly, but they can't take heating nearly as well.



IEEE spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

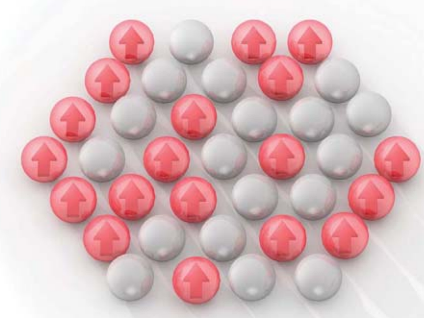
# MIX and MATCH

Nanocomposite magnets, like many other composite materials, combine two substances with complementary properties



## 1. MAKE PARTICLES

One set must be magnetically "hard" [red]; the other set [gray] must be strongly magnetized.



## 2. COMBINE THEM

Align the hard particles and mix them with the strongly magnetized ones.

Neodymium magnets have improved steadily over the three decades since they were invented, but they're now reaching their limits. Materials of this type have a theoretical maximum energy product of 64 MGOe, and scientists from Neomax Materials Co., in Japan, have already produced a neodymium magnet with 92 percent of this value. There's just not that much room for improvement.

Some yet-undiscovered combination of elements may well beat out neodymium-iron-boron. But searching for a new wonder substance isn't the only path to a great magnet. Around 1990, a group of Soviet researchers led by Nikolay Manakov, a physicist currently at Orenburg State University in Russia, and independently, Eckart Kneller and Reinhard Hawig from Ruhr University in Germany proposed an altogether different approach. Their idea was to juxtapose two different magnetic materials, one having a high coercive field, the other a high saturation magnetization. If this was done on a fine enough scale, they thought, exchange forces from the former would magnetically stabilize the latter. As with more familiar composite materials, two different components mixed together can serve much better than either one can alone.

For a composite magnet to work, the high-saturation material can't be any more than 10 or 15 nanometers thick. Otherwise, exchange forces won't reach far enough into its interior. Although no such restriction exists for the stabilizing component, you won't get much of it adjacent to the high-saturation stuff unless it's finely broken down, too.

Such nanocomposite magnets promise higher saturation magnetizations—and in turn, higher maximum energy products—than today's best neodymium magnets. As far back as 1994, researchers calculated that using an iron-cobalt mixture for the high saturation magnetization it provides and stabilizing it with a samarium-iron-nitrogen alloy could produce magnets with maximum energy products as large as 137 MGOe—more than twice the current record. In addition, such magnets would require much smaller amounts of rare earth elements and would better resist corrosion, a notable problem with today's high-performance magnets.

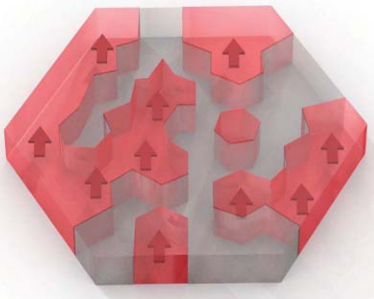
You might guess that mixing two different metallic alloys on the nanoscale would require ultramodern fabrication techniques. In fact, materials scientists have long known how to get such combinations to form without having to create them from nanometer-size building blocks, and researchers have explored those techniques—including ultrafast solidification, mechanical alloying, and sputtering—to fabricate nanocomposite magnets. But so far, the resultant maximum energy products haven't approached the whopping values theorists predict are possible.

One problem is that it's almost impossible to make the bits of the high-saturation material small enough and to position them so that they're always surrounded with high-stability material. The other stumbling block is the poor alignment—or even the complete lack of alignment—between the easy directions of magnetization in the high-stability material. And when the theorists calculated those stupendously high values for the maximum energy product, they assumed perfect alignment.

GIVEN THESE challenges, it's no surprise that past attempts have failed to create a good nanocomposite magnet. That's why in recent years researchers have begun thinking seriously about producing such a magnet from the bottom up—that is, by first synthesizing nanometer-size magnetic particles and then assembling them.

Chemical techniques could work for that. In 2000, for example, a group of scientists at IBM under the direction of Shouheng Sun chemically synthesized high-saturation-magnetization nanoparticles of an iron-platinum alloy, a rather exotic (and extremely expensive) permanent-magnet material. That encouraged other chemists to try to do the same for samarium-cobalt and neodymium-iron-boron alloys. So far, those researchers have had no luck. Recently, Sun, who is now at Brown University, and J. Ping Liu, from the University of Texas at Arlington, have managed to synthesize samarium-cobalt nanoparticles, but those particles were stuck together in clumps, making their use in nanocomposite magnets problematic.

BRYAN CHRISTIE DESIGN



## 3. CONSOLIDATE

Use heat and pressure to compact the mixture into a dense magnet.

We are also trying to build composite magnets from the bottom up. But we make nanosize magnetic particles using a variation on a standard metallurgical technique: ball milling. When a powdered substance is stirred, tumbled, or shaken in a vial filled with steel balls, the particles usually break up but sometimes stick together. The trick is to do the milling in a liquid that resembles gasoline, to which a small amount of a fish-oil-like surfactant is added. That greatly reduces the tendency of the particles to stick together, because the surfactant molecules surround the particles, keeping them apart.

Such surfactant-assisted ball milling can produce magnetic particles that are only a few nanometers across. We have also managed to obtain samarium-cobalt flakes that are a few tens of nanometers thick, which should work well as the high-stability component in a composite nanomagnet. We can easily produce large quantities of these magnetic flakes, but we continue working to control their sizes better and to figure out ways to protect them from oxidation, which acts fiendishly fast with things this tiny.

Our ideas for how these particles could be combined with others of high saturation magnetization and how the resulting mixture could be consolidated into dense nanocomposite magnets are admittedly somewhat sketchy. Twice, in 2002 and in 2007, groups that included researchers from Georgia Tech, IBM, Iowa State University, Louisiana Tech University, the University of Texas, and Chiba Institute of Technology, in Japan, employed similar techniques to fabricate nanocomposite magnets. But they used two different iron-platinum alloys, which resist oxidation. Because those particles were assembled randomly and because the chosen high-saturation particles had a magnetization that wasn't all that high, the magnets they made didn't perform well.

One relatively simple way to assemble these two kinds of particles is by depositing the high-saturation ones as a thin coating on high-stability cores. The easy direction of magnetization of the cores would have to be aligned in an applied magnetic field before the mixture was compacted. The particle coatings would then merge into a network of thin layers. In an experiment carried out in cooperation with Electron Energy Corp. of Landisville, Penn., we tested this idea by coating relatively coarse copper particles with iron nanoparticles. After compacting them at high temperature, we observed just such a network of thin iron layers inside a piece of copper. Copper isn't magnetic, though, so the result wasn't a permanent magnet. But this experiment provided a convenient way to test our ideas and procedures.

The problem with this approach is that it works well only when the cores dwarf the particles in the coating. This means that only a small amount of the high-saturation material can be added. So any nanocomposite magnet made this way, assuming that all other difficulties are trumped, would not be much better than magnets made from whatever material is used for the cores.

WE AND other researchers clearly need to explore other approaches if we truly want to make real strides. One possibility is to use surfactants more cleverly so that one set of magnetic particles becomes negatively charged on their surfaces while the other set becomes positively charged. Mixing the two kinds of particles in a liquid in the presence of a magnetic field might then give the desired arrangement, with particles of one type alternating with particles of the other, with the easy directions of magnetization neatly lined up.

The problem with using a surfactant to assist in assembling nanoparticles is that the molecules of the coating would be very much out of place in the final magnet. At best, they would dilute its magnetization. At worst, they might even react with the rare earth element, destroying its stabilizing effect. So we would expect that the surfactant molecules would have to be removed after assembly, either by dissolving them chemically or by heating the mixture until these molecules decompose or evaporate.

Assuming that the desired nanoparticle assemblies could be arranged in this way, the results still wouldn't make for very good permanent magnets: They would neither be mechanically strong nor sufficiently dense. Somehow you'd have to compact them, a step that we don't think would be any easier than the preceding ones. If you use only pressure to do that, for example, the pressures would need to be impractically high, because hard alloys like samarium-cobalt are exceedingly difficult to pack together. You'd need to use explosives to achieve the required amount of squish, and that doesn't make for an orderly assembly line! A combination of pressure and heat would probably work better, but heating might coarsen the particles or initiate unwanted chemical reactions.

This list of obstacles gives you an idea why progress in the not-so-young quest for nanocomposite magnets has been advancing so slowly. But thanks to more than a few incremental successes, we not only understand what we want to achieve, we also clearly see a path to getting there. There is a feeling within the community of researchers working on this problem that any day now our efforts will be rewarded with an impressive next-generation supermagnet. And even if that great magnet of the future proves a long time coming, we are still bound to find a way to make it, one tricky step at a time. Get your refrigerator ready. ❏

**JOIN THE DISCUSSION** *Post your comments at* http://spectrum.ieee.org/magnets/0811



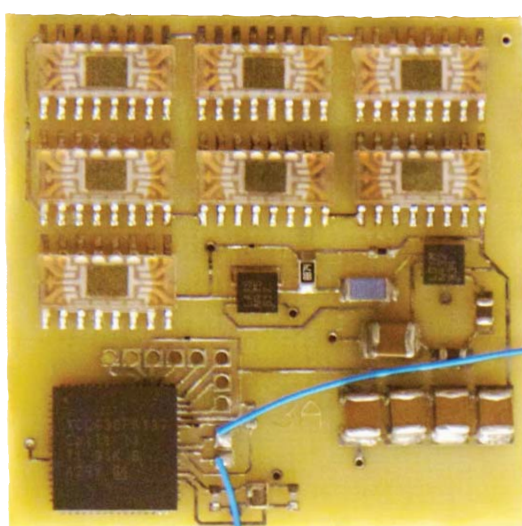
spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®


**IN FLIGHT:** NASA astronaut Andrew Feustel installs a materials science experiment pallet on the outside of the International Space Station. The box includes three prototypes of integrated circuit spacecraft. The spacecraft prototype at right was photographed before installation on the space station.

*PHOTOS: LEFT, NASA; RIGHT, ZAC MANCHESTER*

# CHIPS IN SPACE

## HOW SATELLITES THE SIZE OF CHIPS COULD REVOLUTIONIZE THE WAY WE EXPLORE SPACE



+ BY MASON PECK +



IEEE spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

# GRAVITY MAY BE WOVEN INTO THE VERY FABRIC OF SPACE-TIME, BUT SOME OBJECTS SEEM NEARLY IMMUNE TO ITS PULL

**SCALE SOMETHING DOWN** to the size of a dust particle and you'll find it can stay aloft almost indefinitely, dancing in midair on thermal currents. With matter that size, the force of air striking the surface of the particle outmatches gravity's effect on its tiny mass.

This behavior is more than just a curiosity: It could have profound implications for space exploration. Spacecraft have been getting bigger and bigger for decades, ballooning in size to carry ever more impressive equipment, from the Herschel Space Observatory's 3.5-meter telescope to the Cassini probe's 11-meter magnetometer boom. But if we can reverse that trend and instead build the tiniest spacecraft possible, we can create entirely new ways to study the solar system and beyond.

Miniaturization will inevitably mean limitation—less power, fewer instruments, and reduced ability to store and broadcast data. But dust-mote-size spacecraft could do things that no current space probe can do: coast without a parachute onto the plains of Mars or float for weeks in the soupy atmosphere of Titan. They could be mass-produced and launched by the thousands to form vast space-based networks of sensors. And if the probes could be made thin and lightweight enough, alternative forms of propulsion could eventually send them to distant worlds, without the need for rocket fuel.

In the fall of 2005 at Cornell University, graduate student Justin Atchison and I set out to create such miniature spacecraft. The aim of our project, called Sprite, is to fit everything a satellite might need on a 1-square-centimeter integrated circuit. The project finally took its first step into space on 16 May of this year, when the space shuttle *Endeavour*, on its final mission, carried three of our prototypes to the International Space Station. We'll find out in a couple of years how these first chips withstood the rigors of space. If all goes well, we then plan to launch smaller Sprites into orbit on their own, where they can be used to test new forms of propulsion that could ultimately take them to other planets.

**SPRITE IS THE FIRST** spacecraft-on-a-chip project to launch a prototype, but ours isn't the only group exploring the potential of miniature spacecraft. The idea goes back at least 15 years, and it has its origins in "smart dust"—tiny microelectromechanical sensor systems that can be used to measure light and temperature, register movement and location, and detect chemical and biological substances. The notion of sending such systems into space was slow to gain momentum. But it began to take off once space researchers realized that integrated circuits had become quite inexpensive, dense, and easy to fabricate, and that almost everything a spacecraft needs can now be made with semiconductors alone: solar cells for power, capacitors for energy storage, and all the memory and processing capability you could want. As with smart dust, a diversity of payloads can be fabricated to ride on a chip, including basic spectrometers, load sensors to measure particle impacts, chemical sensors, and simple CMOS cameras. Researchers around the world, including groups at Surrey Space Centre, the University of Strathclyde, the Aerospace Corp., and the Jet Propulsion Laboratory, have explored the possibility of making chip-based spacecraft and are investigating their capabilities.

Our Sprite prototypes weigh about 10 grams, but their successors will ultimately weigh between 5 and 50 milligrams and will likely be able to carry just one simple sensor each. At that size, a single Sprite will never be able to rival the data-gathering capability of such precision instruments as the Hubble Space Telescope. But we envision launching these tiny, easy-to-fabricate chips en masse to form something new: distributed sensor networks.

We could, for instance, send tens of thousands of Sprites into orbits between Earth and the sun. These simple chips would have one task: to send a signal to Earth when the local magnetic field or the number of charged particles that hit the spacecraft exceeded some threshold. Taken alone, each chip would provide just one data point. But a network of these scattered chips could produce 3-D snapshots of space weather, something no traditional spacecraft, no matter how sophisticated, could ever do on its own. A payload of a million of the relatively heavy 50-mg version of the Sprite would amount to just 50 kilograms, about the mass of a single science instrument on one of NASA's larger interplanetary spacecraft. So the launch costs of a Sprite network would be significantly lower than that of a traditional satellite.

**LAUNCHING A MILLION SPRITES** would be pointless unless a substantial number of them could survive the many hazards of space, including charged particles, micrometeorites, and extreme temperature swings. Their hardiness is one of the things we hope to gauge in our current experiment aboard the space station.

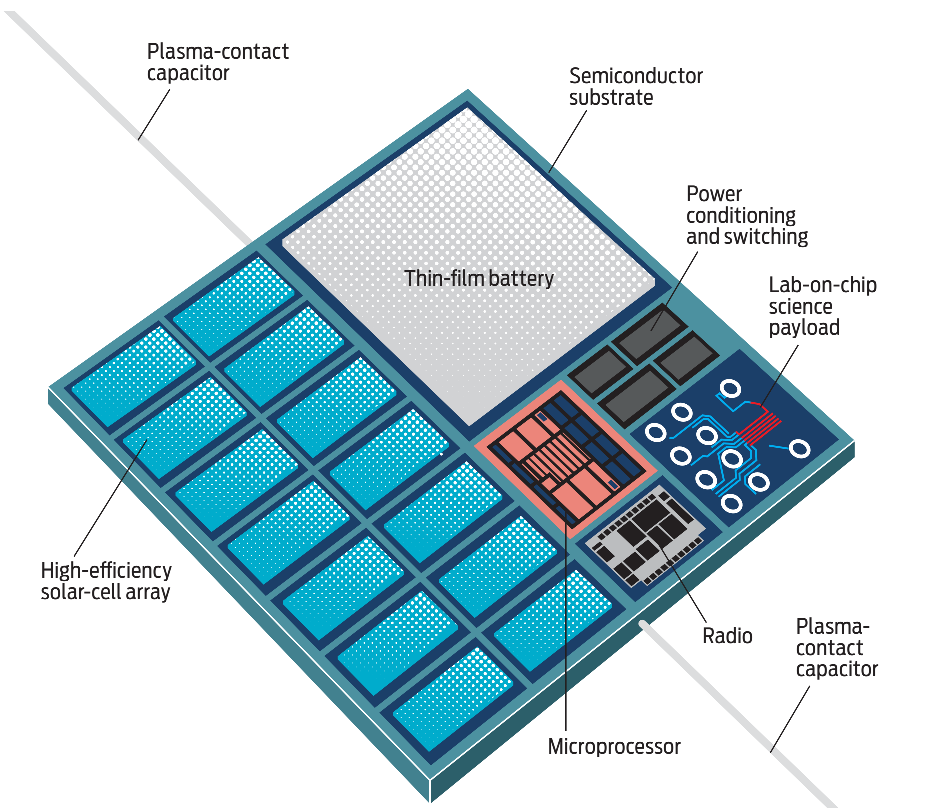
The Sprite prototypes have been mounted on the exterior of the ISS on a materials-science pallet called MISSE-8, which stands for Materials on International Space Station Experiment 8. Fabricated by hand in the lab, each prototype measures 3.8 cm on a side and contains seven tiny solar cells, a microprocessor with a built-in radio, an antenna, an amplifier, and switching circuitry to turn on the microprocessor whenever there's enough stored energy to create a single radio-frequency emission—a digital "beep." We'll use the timing of the Sprites' beeps to tell us the sun's angle of incidence on the chip. The more oblique the angle, the longer it will take for the chip's capacitor to charge. Measuring the time between beeps will give a rough measure of the chip's orientation to the sun.

Beyond just telling us how well the Sprite components survive in space, the experiment will reveal whether the 902-megahertz radio pulses that the chips emit can be detected on the ground. The transmitters on the prototypes must operate on very little power: The capacitors store just 1 microjoule of energy, enough to power a 100-watt lightbulb for about 10 nanoseconds. As a result, the signals are weak, only 7 percent as strong as the buzz of background noise coming from the sun and man-made sources.

To pick up this subtle signal, we need a way to make it unique and easy to extract. The best technique for the job is a technology called code-division multiple access (CDMA), more commonly used in GPS and cellphone signal processing. With CDMA, every bit of data that a given Sprite transmits is converted into a sequence of shifts in the timing, or phase, of the radio signal. These "m-sequences" will make it easier to pull the signal out from noise. They will also allow listeners on the ground to differentiate one Sprite from another, because the patterns are as unique as fingerprints, and each chip gets just one. CDMA will thus allow many Sprites to share the same carrier frequency and transmit signals to the same ground receiver, just as it lets hundreds or even thousands of cellphone users place calls at the same time.

Expanding each bit into an m-sequence should make up for the Sprites' power limitations. That's because the longer the sequence, the more powerful it will be: The signal strength is effectively integrated over time. We calculated that signals coming from the space station should be fairly easy to detect if each bit is split up into a sequence of 512 phase shifts. Such sequences take a few milliseconds to send. Sprites that are farther from Earth will need to use longer sequences to transmit each bit. A Sprite in orbit around Jupiter, for example, will likely need a full day to send a signal that can be picked up on Earth. But the chip would be able to do that with a transmitter that draws only a few milliwatts of power. With thousands of Sprites in orbit, kilobits of data can be sent each day, but it would take many millions to rival the transmission rate of conventional spacecraft. NASA's Cassini orbiter, in orbit around Saturn, can send as much as 165 kilobits of data back to Earth each second.

**BECAUSE OF THEIR POWER LIMITATIONS,** it will be difficult to create Sprites that can communicate with one another fast enough for them to operate as a collaborative swarm. But the spacecraft could still stay close together as they travel through the solar system by taking advantage of what's known as the Interplanetary Transport Network. The network consists of pathways that wind through space according to the gravitational potentials of the planets. For a cluster of Sprites, the pathways would act like ocean currents, binding them together and sweeping them along as if they were a colony of plankton.




## The Space Chip

All the basic equipment a spacecraft needs could fit on an integrated circuit. This sketch shows what a 1-square-centimeter Sprite could ultimately carry. The chip includes a simple chemical detector and wires for magnetic propulsion.

JAMES PROVOST



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

Sprites would have other ways of getting around. Although carrying onboard propellant is impractical, the Sprites' diminutive size will make them ideal for harnessing the sun's radiation pressure. Photons carry momentum, and when they strike a surface, they transfer that momentum as force. This force blows dust particles out of the solar system and has also been used to adjust the trajectories of interplanetary probes, including NASA's Messenger spacecraft, which entered orbit around Mercury in March.

The basic physics that would propel a Sprite is the same as for cosmic dust. Sprite propulsion relies on the fact the surface area of an object does not shrink as fast as its volume. Halving the radius of a uniform ball, for example, will reduce its volume by a factor of 8, but it will drop the surface area by only a factor of 4. As an object shrinks in size, this property of geometry favors forces that operate on the surface, such as aerodynamic drag, allowing them to more easily overcome the object's inertia.

With a big enough ratio of surface area to volume, a spacecraft could be propelled just by solar radiation pressure. That's the basic idea behind a solar sail, a spacecraft that employs large, thin sails to boost its surface area to catch as much sunlight as possible.

For decades, solar sails were little more than notions, but in the last few years, both NASA and Japan's space agency, JAXA, have successfully demonstrated the technology. The large sails remain folded during launch and are unfurled in space. Solar sails are difficult to deploy and are often quite delicate. Japan's IKAROS spacecraft, which launched in 2010, used a 14-meter-wide polymer sail that was just 0.0075 millimeter thick.

If a Sprite could be made thin enough, then its entire body could act as a solar sail. We calculate that at a thickness of about 20 micrometers—which is feasible with existing fabrication techniques—a 7.5-mg Sprite would have the right ratio of surface area to volume to accelerate at about 0.06 mm/s², maybe 10 times as fast as IKAROS. That should be enough for some interplanetary missions. If Sprites could be printed on even thinner material, they could accelerate to speeds that might even take them out of the solar system and on toward distant stars.

**THE LOW MASS OF SPRITES** should also allow them to harness the magnetic fields that surround planets and pervade the solar system. In this case, they'd be taking advantage of the Lorentz force, which bends the paths of charged particles that move in the presence of a magnetic field. Like radiation pressure, the Lorentz force dominates the dynamics of very small bodies. The effect is evident in pictures of the rings of Saturn, where sunlight and plasma have ionized dust particles. Saturn's magnetic fields tug on these electrically charged particles, pulling them into streams or "spokes" that cut across the planet's rings.

A Sprite would need an electric charge to take advantage of this property of electromagnetism. In Earth orbit, charging a Sprite could be as simple as establishing a potential, via a power supply, between two wires that extend from the chip; the plasma in Earth's ionosphere would do the rest. Lightweight free electrons would quickly neutralize the Sprite's positive wire, but the heavier and slower positively charged ions wouldn't be able to discharge the negative wire as quickly, leaving the spacecraft with a net negative charge. This charge would be maintained as long as the Sprite continued to power the wires.

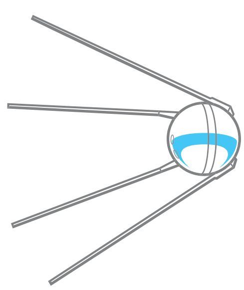
At Cornell, we have begun testing this charging process by exposing Sprite-size spheres to a stream of xenon plasma. The setup mimics conditions in Earth's ionosphere, and our early results suggest that the charging technique will work. If it can be accomplished in Earth's orbit, Lorentz propulsion could allow Sprites to rendezvous with other satellites without releasing exhaust plumes that could damage delicate equipment. Charged Sprites would also be able to change their orbital inclination, enabling the chips to enter an equatorial or polar orbit regardless of their original launch location. Sprites could also raise their orbits, to counteract the tug of Earth's atmosphere, and they might even escape Earth's gravity entirely if the charge is high enough.

A more spectacular application of Lorentz propulsion could turn Jupiter into a particle accelerator. Jupiter's magnetic field

## The Satellite Size Spectrum

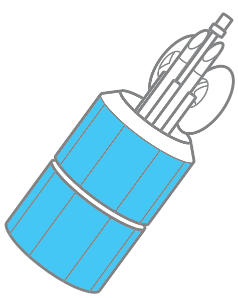
As space applications have grown, so has satellite diversity. The spacecraft shown here are all too large to effectively use planetary magnetic fields or solar pressure for propulsion. Sprites, if they could be made to weigh less than 50 milligrams, could do both.

**SPUTNIK 1**
*First artificial satellite*
**MASS:** 83.6 kilograms
**SIZE:** 58-centimeter-diameter sphere, with whiskerlike antennas measuring 2.4 and 2.9 meters



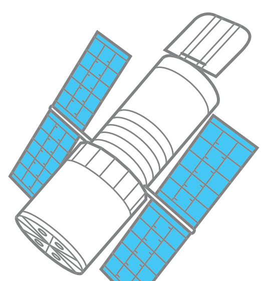
1957

**INTELSAT 4 F-3**
*International communications satellite*
**MASS:** 1410 kg
**SIZE:** 5.3 meters long, with antenna



1971

**HUBBLE SPACE TELESCOPE**
*World's most massive space telescope*
**MASS:** 11 110 kg
**SIZE:** 13.2 meters long



1990

is 20 000 times as powerful as Earth's, and so a charged Sprite could use this magnetic field to accelerate itself in orbit around the planet. Once it reached speeds of a few hundred or thousand kilometers per second, the chip would turn off its supply of power to the wires. Jupiter's magnetic fields would then no longer confine the spacecraft, and it would be flung out of its orbit and indeed out of the solar system.

Sprites may be able to accelerate fast enough to reach the nearest star system, Alpha Centauri, in a few hundred years. That might not seem impressive; the speedup process itself could take decades, and the Sprites would arrive beyond any of our lifetimes. But consider the alternative: Solar sails, which have long been considered for interstellar trips, would take at least a thousand years—and probably a lot longer—to make such a journey.

**POST YOUR COMMENTS** *online at* http://spectrum.ieee.org/spacechip0811

**INTERSTELLAR EXPLORATION** may be a long way off, but the idea of miniaturizing spacecraft isn't speculative. Even as the largest spacecraft have been getting bigger, there has also been substantial interest and investment in smaller spacecraft. One of the most compact designs now in use is the CubeSat, an open-architecture, grapefruit-size spacecraft weighing no more than a kilogram. Dozens of CubeSat-based university research projects have now been launched into space.

The main advantage of a CubeSat is that it's cheap to build and launch. And because multiple CubeSats can fit on the same rocket, the launch costs can be shared. This strategy has reduced the price tag of sending a payload into space to about US $100 000, a fraction of the cost of sending a traditional telecommunications satellite, weighing hundreds of kilograms, into orbit. Sprites will continue this trend, allowing tens of thousands of spacecraft to be launched for the price of a single CubeSat.

But spacecraft-on-a-chip projects have very different aims from those of CubeSat and other such efforts. Our main goals are to exploit the physics of small objects and the power of mass production. In that sense, Sprite represents a paradigm shift.

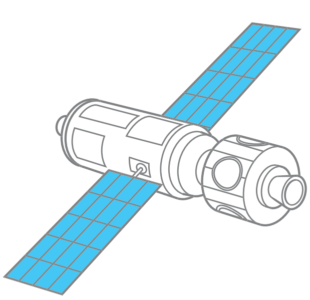
Rather than hand building one-of-a-kind spacecraft, we envision constructing spacecraft on wafers in much the same way that common integrated circuits are made today. During fabrication, solar cells and other components would be incorporated with microelectromechanical systems techniques. Instead of exhaustively testing each part, as is done with current spacecraft, engineers will be able to monitor Sprite quality in a less labor-intensive fashion by using statistical process control, testing a few chips from each batch to make sure they meet specifications.

Of course, chip-scale spacecraft would have some downsides. Like larger satellites, out-of-commission Sprites would contribute to the growing collection of space junk until atmospheric drag brought them back to Earth. Fortunately, Sprites in low-Earth orbit should reenter within a few days. To make missions last longer, magnetic torque coils could help orient chips so that they fly edge-on around the planet. When a Sprite reached the end of its mission, this attitude control system would turn off and the chip would turn to orbit face-on, boosting the drag it experiences. Without a parachute, a 50-mg Sprite would burn up on reentry, but Sprites weighing closer to 5 mg could flutter back down to Earth intact.

Sprites will also be far more vulnerable to damage than present-day spacecraft. Because they are lightweight and have solar cells built directly on the chip, Sprites can't be equipped with radiation shielding to protect their electronics. This lack of shielding also makes the chip more vulnerable to impacts with micrometeorites, which zip at high speed throughout the solar system. Sprites could compensate for these hazards through sheer numbers; missions could be designed so that a significant fraction of the chips could be lost without dooming the operation.

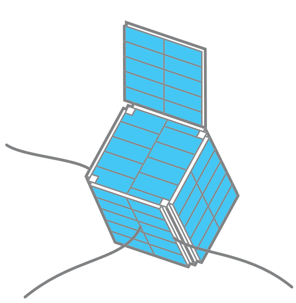
That's a fundamentally different way to explore space. Right now, we invest hundred of millions and sometimes billions of dollars in one-off satellites that are meticulously designed to survive a range of contingencies. But if we allow some failure here and there, we will open up intriguing new possibilities for investigating the universe. ❑

**ZARYA**
*First International Space Station module*
**MASS:** 19 323 kg
**SIZE:** 12.6 meters long



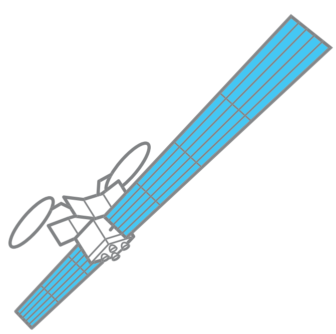
1998

**CUTE-1**
*One of the first standardized miniature CubeSats*
**MASS:** 1 kg
**SIZE:** 10-cm-wide cube



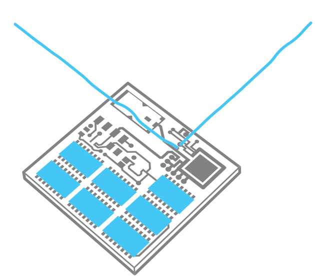
2003

**XM-3**
*Commercial radio satellite*
**MASS:** 2800 kg
**SIZE:** 47.9 meters from the end of one solar panel to the other



2005

**SPRITE PROTOTYPES**
*Test chips attached to International Space Station*
**MASS:** 10 grams
**SIZE:** 3.8- by 3.8-cm boards

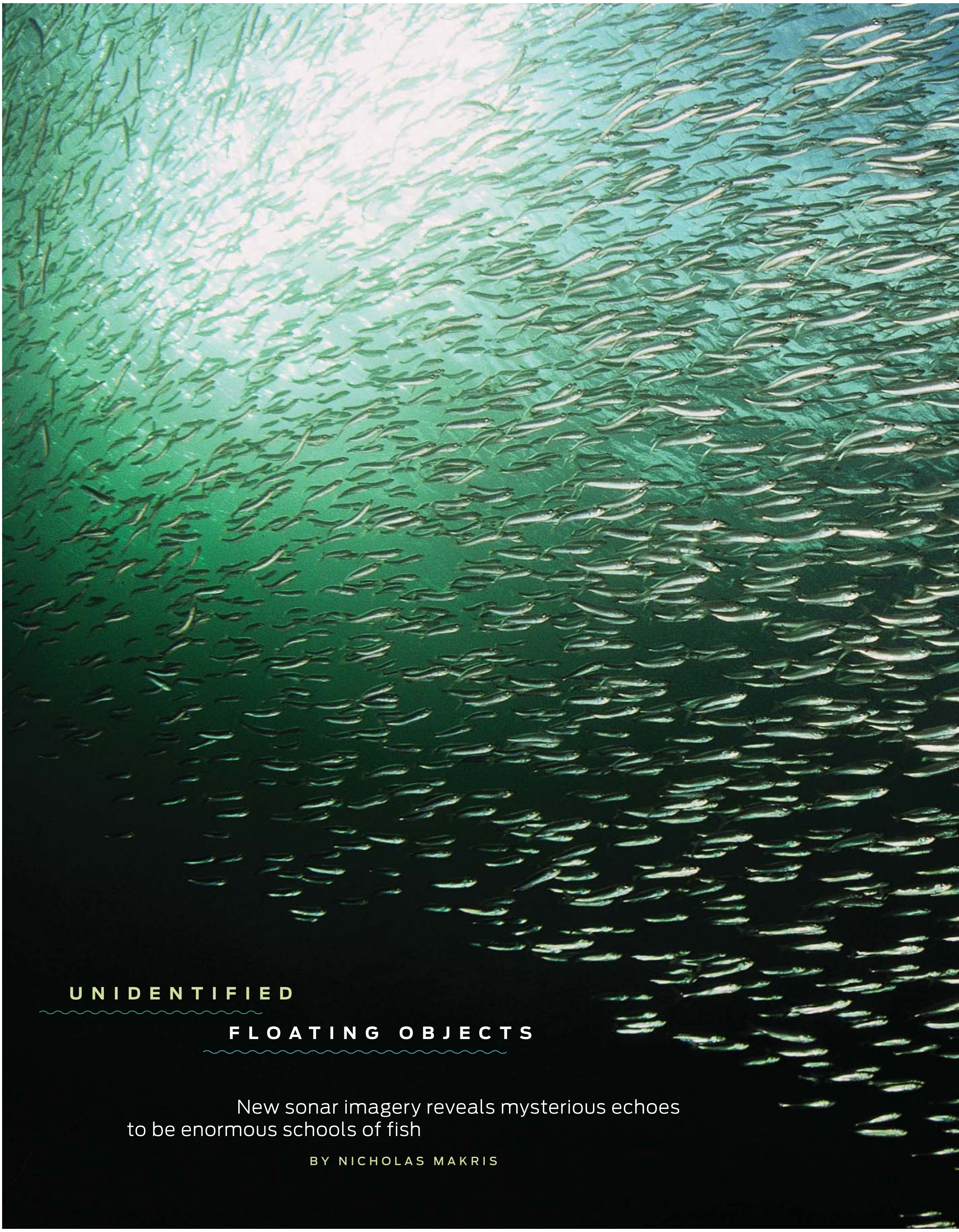


2011

JAMES PROVOST



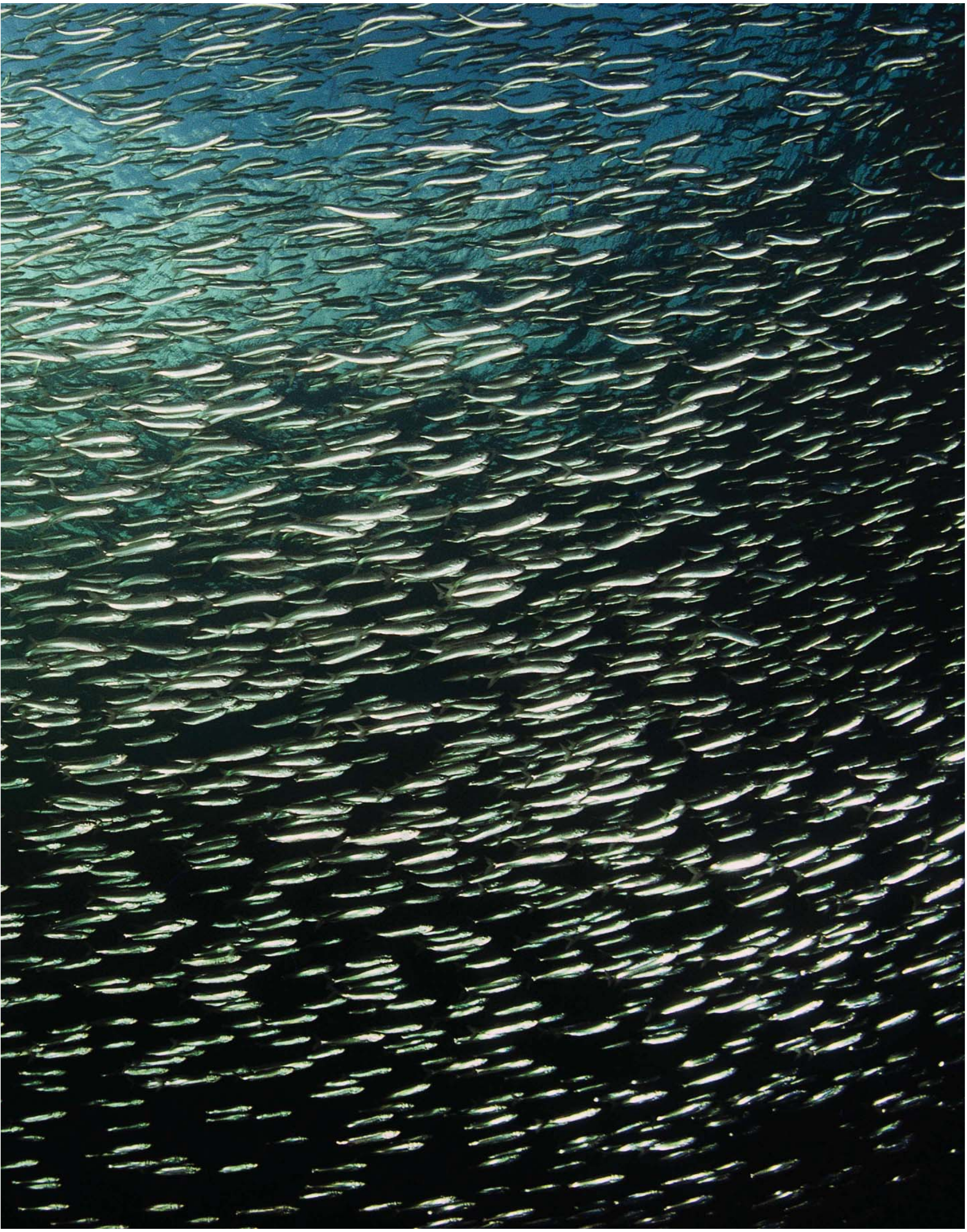
spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page



# UNIDENTIFIED FLOATING OBJECTS

New sonar imagery reveals mysterious echoes to be enormous schools of fish

BY NICHOLAS MAKRIS





ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®

EARLY ON A MAY MORNING BACK IN 2003, I WAS ON the research vessel *Oceanus* some 200 kilometers south of Long Island, N.Y., searching for something I had been chasing for years. It wasn't a white whale, but it was just as alive—and a whole lot bigger.

My scientific colleagues and I had jokingly referred to the enigmatic thing we were seeking as a UFO—for "unidentified floating object." To find our elusive prey, we had engineered a newfangled sonar system that operates at relatively low frequencies and installed it on *Oceanus*, which is operated by the Woods Hole Oceanographic Institute. After days at sea, we finally got our big break—strong echoes emanating from about 20 km south of our ship, where the water was roughly 100 meters deep. On our sonar displays, it looked as though something the size of Manhattan was perched near the edge of the continental shelf.

In some places, the seafloor sports some pretty rough topography, but our charts showed it to be flatter than Kansas around where we were. And the mysterious echoes we were seeing with our new sonar hadn't been apparent the previous day, so they couldn't have come from any sort of uncharted seafloor ridge. What's more, as we stared at the display for the next hour or so, we could see the structure it revealed gradually changing shape, which seafloor geology just doesn't do.

This was definitely a UFO, one the size of a large city. Such things had been detected before with other long-range sonars, and most specialists at the time believed that these enigmatic echoes stemmed from irregularities on or beneath the seafloor. These acoustic ghosts came and went, it was thought, because changes in the temperature or salinity of the ocean caused varying refractions and either strengthened or weakened the echoes. We had never believed that particular ghost story and suspected that these strange acoustic reflections in fact came from large groupings of fish. Here at last was our chance to find out.

We immediately radioed the news of our UFO sighting to colleagues on another ship that was equipped with conventional echo sounders, similar to the kind countless boaters use to check the depth of the water and to locate schools of fish. It took that ship hours to reach its target, but when it finally did, shouts came back over the radio: "It's fish!" We were seeing a massive shoal—a community of oceanic fish—in its entirety for the first time. The echo-sounding equipment available on most ships has a limited range and is able

PREVIOUS PAGES: FRED BAVENDAM/GETTY IMAGES



ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page

**Follow the Fleet:** The author's long-range sonar system required two ships [left]; a third was needed to confirm that the reflections measured came from fish. Researchers examining the sonar data [top] were able to monitor large congregations of fish as they formed. The author and his colleague Yisan Lai [bottom] helped ready the ship that towed the source of the sonar.
*PHOTOS: MIT LABORATORY FOR UNDERSEA REMOTE SENSING*

to sense only tiny bits and pieces of such large shoals. So until that time, nobody knew what such a large shoal looked like.

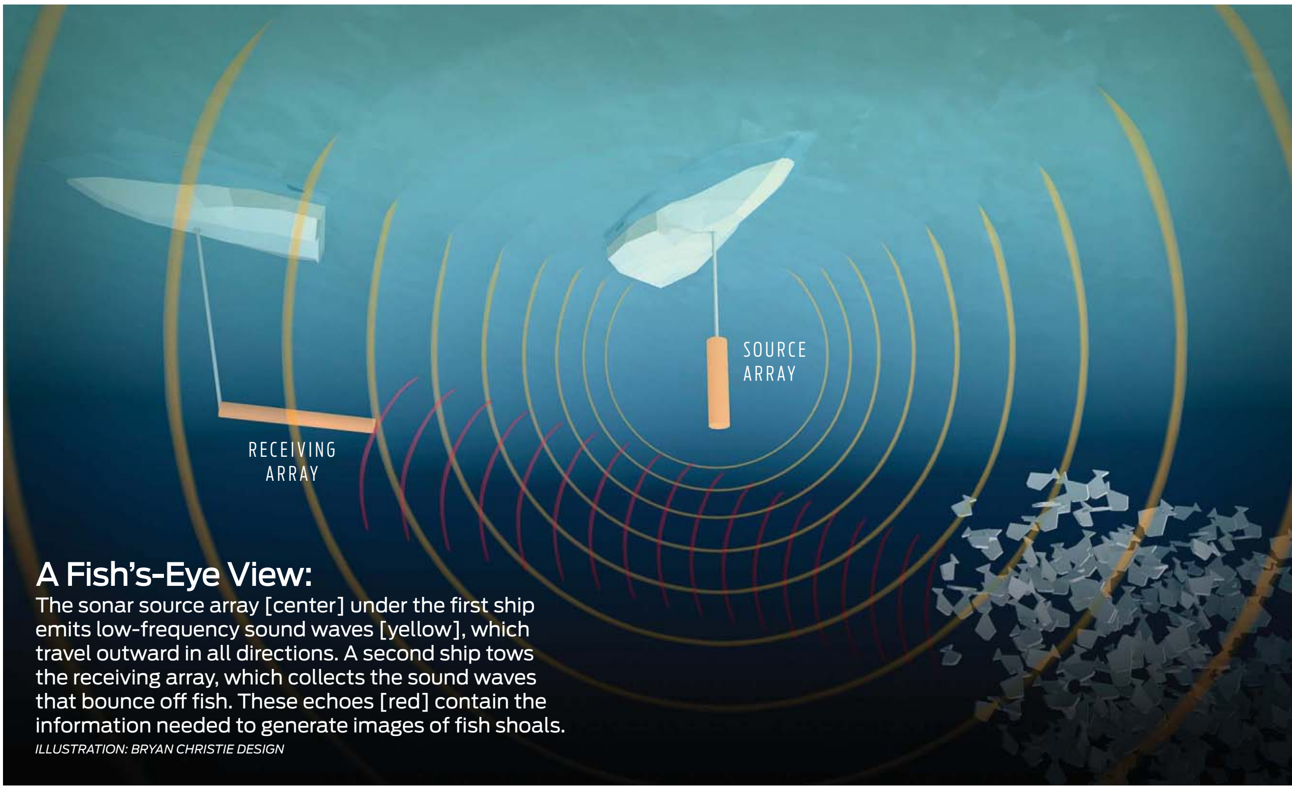
We were all immediately struck by the implications. These fish had come together in a group that was more vast than anything that had been seen before. And they were doing it in a very unexpected place: a shipping lane leading to New York Harbor, one of the busiest ports in the world.

I felt honored to have helped make this discovery in 2003, but almost immediately those feelings became mixed with ones of deep concern about how the new technology could be misused. These thoughts crystallized during a later expedition when our long-range sonar equipment detected strong echoes in the vicinity of Georges Bank, off Massachusetts, which had been a prolific source of cod and halibut for centuries before overfishing caused those fisheries to collapse. As before, we radioed another vessel with conventional echo sounders to investigate, and it confirmed that the echoes were indeed coming from a giant collection of fish. But soon after, the captain called me to the bridge and pointed to the radar screen. On it were blips that marked the positions of dozens of fishing boats that had converged on the spot of the enormous fish congregation after listening in on our radio communications, which we had naively sent on an open maritime channel.

That episode made it very clear that this new fish-finding sonar could wreak havoc on ecosystems around the world. Used responsibly, though, it could help marine biologists and fisheries managers follow fish populations in ways that were previously unimaginable.

THE SONAR SYSTEM MY MIT COLLEAGUES AND I PUT together to chase UFOs is just the latest link in a long chain of technical developments that date back to World War I, when submarines first came into widespread use. With the advent of undersea warfare came an urgent need to detect, localize, and image submerged objects, sometimes over vast oceanic regions.

Of course, light doesn't penetrate far in seawater. The same is true for all but the longest radio waves. So the only practical way to sense distant objects is to use sound, which can travel great distances underwater—a fact that has been known for hundreds if not thousands of years. That's why governments around the world have for decades poured huge sums into studying the physics of long-range sound propagation and scattering in the ocean.



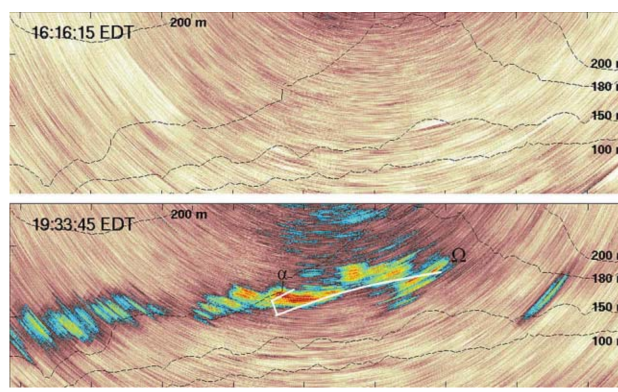

**A Fish's-Eye View:**
The sonar source array [center] under the first ship emits low-frequency sound waves [yellow], which travel outward in all directions. A second ship tows the receiving array, which collects the sound waves that bounce off fish. These echoes [red] contain the information needed to generate images of fish shoals.
*ILLUSTRATION: BRYAN CHRISTIE DESIGN*

As a result, naval sonar systems grew increasingly sophisticated during the 20th century. By the late 1960s and early 1970s, some side-looking sonar systems were able to form images across several kilometers of ocean, revealing the first hints of unidentified floating objects. Some people hypothesized that these echoes came from fish, but that surmise hadn't been confirmed. By the 1980s and early 1990s, long-range submarine-hunting sonars gained the ability to scan the ocean in a full 360 degrees in azimuth, imaging the entire horizontal plane around them. By this time the navies of the world had begun to be really troubled by the many ghostly reflections these systems were detecting—things that had no ready explanation.

At this point my group at MIT became involved in a large experimental program sponsored by the U.S. Office of Naval Research, which included deep-ocean surveys around the Mid-Atlantic Ridge, the undersea mountain system that runs through the center of the Atlantic Ocean. There, we found that previously uncharted ocean ridges caused many of the UFOs we were seeing on our sonar screens.

Our sponsors in the Navy were thrilled. And they were eager—too eager as it turns out—to apply the lessons learned to explain sonar UFOs found in much shallower water, above the continental shelves. The problem was that most of those shelves, the underwater extensions of many continents, are essentially featureless plains, and they are very well charted. So it made no sense to blame UFOs on unknown seafloor topography. Many people in the Navy concluded that hidden geologic features of the continental shelves must cause these ghostly sonar reflections to form.

To test that idea, the Office of Naval Research wanted us to use our long-range sonar to take snapshots of the ocean off New York City. During the last Ice Age, when the sea level was much lower than it is today, the Hudson River and its various tributaries flowed over what is now the continental shelf. Our Navy contacts hoped to find out whether any unusual acoustic reflections appeared near buried river channels. We were skeptical. We even published a prediction that the channels of ancient rivers wouldn't cause unusual sonar readings. According to our calculations, sound waves lose too much energy when traveling through the sediments that cover buried riverbeds: They couldn't possibly appear as large floating objects on sonar.




**Ghost Object:**
From a sea of acoustic noise [above, center], a large concentration of sound scatterers forms within just hours [bottom].
*IMAGES: MIT LABORATORY FOR UNDERSEA REMOTE SENSING AND NORTHEASTERN UNIVERSITY LABORATORY FOR ACOUSTICS AND REMOTE SENSING (2)*

It took us years of detailed survey work and analysis to show the Navy that there was no more than a random correlation between river channels and UFOs, so the former couldn't cause the latter. This conclusion disappointed many researchers with an interest in studying seafloor geology—and put us in the hot seat. If not buried geology, what was causing these strange echoes to form? For a while, we had only our hunches. But the next time we went to sea with our equipment, we came prepared: We brought an extra ship with conventional fish-finding sonar to collect hard evidence. And our discovery in 2003 that shoals of fish were responsible for UFOs put an end to the debate.

A CONVENTIONAL FISH-FINDING SONAR WORKS AT ultrasonic frequencies, well above the audible range. It directs an ultrasonic beam, like a flashlight's, on marine life. Such systems can provide high-resolution images of things in the immediate vicinity, often letting you pick out the echoes of individual fish.

The main drawback of these systems is that they work only at short range, typically over distances that are about equal to the depth of water you're in. To detect things farther away, you need to use lower frequencies. For our sonar system, we use audio frequencies that go from roughly the G above middle C (392 hertz) to about two octaves above that (to 1570 Hz).

Our fish-sensing sonar requires two instruments—one to transmit sound waves and one to receive their echoes. The source of the sound waves is a string of what are essentially loudspeakers, which hang vertically below the first ship. The speaker array sends out short bursts of sound that travel in all directions.

These acoustic waves can go hundreds or even thousands of kilometers. On this scale the ocean can't be thought of as an infinite abyss—its average depth is just a few kilometers. And over the continental shelves, the water is only a couple of hundred meters deep at most. So the overall geometry resembles a puddle, only bigger. Any sound waves traveling upward or downward quickly hit a boundary—the surface or the bottom—and bounce back. In this way, the thin veneer of ocean horizontally channels the sound energy we inject into it, guiding the acoustic waves just as effectively as an optical fiber guides the light sent through it.

The sound waves we send out reflect or scatter off the objects they encounter, and a long line of hydrophones (underwater microphones), towed horizontally behind the second ship, pick up these echoes. Careful processing of the received signals allows us to figure out which direction the echoes are coming from and how long the sound waves are taking to make the round trip. With that information, we can form a pretty good picture of what the ocean contains up to about 100 km away.

By taking frequent sonar images of the ocean over time, we're essentially gathering frames of a video; when we play it back, it reveals what hundreds of millions of fish are doing across an area that's hundreds of kilometers across. Modern computers have no problem handling the signal- and image-processing calculations needed to generate these moving images in real time, so we can watch all the subsurface action unfold in front of our eyes.

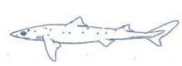
Surveying an area that size with traditional fish-finding sonar would be nearly impossible. You'd have to send out a fleet of fast survey ships working around the clock. Nobody, not even the navies of the world, has money for that. That's why after nearly a decade of surveys near the Georges Bank fishing grounds, no one in the National Marine Fisheries Service ever knew that herring were amassing on such a large scale there each night during spawning season, something we quickly discovered with our long-range sonar.

### Fish Species Found on the Continental Shelf South of New York

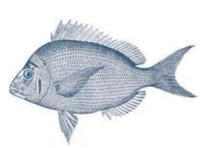

ATLANTIC HERRING


ATLANTIC MACKEREL


BLACK SEA BASS


DOGFISH


RED HAKE


SCUP


SILVER HAKE (WHITING)


SPOTTED HAKE

U.S. FISH AND WILDLIFE SERVICE

STRONG AUTUMN STORMS CURTAILED our 2006 sonar survey of Georges Bank to just two weeks, chilling us with stiff breezes and gale-force winds while we were at sea. During the first week my colleague Purnima Ratilal, of Northeastern University, in Boston, noticed a curious pattern. Each day a shoal of herring would form at roughly the same place and time. To prove it to the rest of us, she said she could tell us precisely when we would see a massive shoal emerge on the northern flank of Georges Bank. At around 5 p.m. that day, she gathered several of us to the sonar display and said, "Just watch, just watch."

From a sea of acoustic darkness, little specks of high-intensity scattering began to show up on the display, just where she said they would be. These specks quickly grew into lines, their endpoints spreading about 10 times as fast as even the most athletic herring can swim. With our long-range sonar, we were able to show in just a few days that these herring shoals formed rapidly and like clockwork. Once the fish reached a critical population density, they began slowly to migrate toward shallow spawning grounds on Georges Bank.

These observations—part of the Alfred P. Sloan Foundation's Census of Marine Life—proved a fundamental theory about the behavior of many animals that travel in groups. They follow a simple rule: Match the average velocity of your fellow fish or birds or caribou or whatever, at least the ones you can see. When population density is low, the animals' spheres of perception don't intersect, so they don't move coherently. But as the population density increases, they start to notice—and to mimic—one another. Chain reactions then cause their motions to become synchronized over the entire group.

The herring we were watching on our sonar were doing exactly that. Once we figured out what was happening, we informed scientists on ships equipped with conventional echo sounders, so that they could investigate these goings-on in more detail. We found that herring generally hid near the seafloor during the daytime. Then, at sunset, they rose a few meters, converged into large shoals, and headed south.

Our best guess was that these fish were coming together each evening to find other herring in a similar reproductive state. Under the cover of darkness, they could then swim to their shallow spawning grounds, but they would return before the sun came up again so that predators could not find them. Our sonar showed exactly how and when they did this, which made us wonder how safe from predators—the human kind—these fish would be if the use of this new technology is not well regulated.

ONCE WE CONFIRMED THAT THE NOVEL properties of our sonar could be used to locate large groups of fish, we wondered what else we could learn with it. Quite a lot, it turns out—enough to distinguish fish of different species. That's because many fish have swim bladders, air-filled sacs that help them regulate their buoyancy as they move between different depths.

The sound waves our sonar generates are longer than even the largest fish, so they don't bounce off a fish's body the way they might reflect from a larger obstacle. But they do cause the fish's swim bladder to resonate. This scatters some of the acoustic energy in all directions. Our receiver picks a fraction of this scattered energy, and from its frequency we can estimate the size of the swim bladder.

Small fish, like herring, capelin, or anchovies, have correspondingly small swim bladders, which typically resonate at frequencies of 1000 Hz or more. Medium-size fish—say, cod, hake, pollack, and salmon—have medium-size swim bladders, which generally resonate at frequencies of several hundred hertz. Fish that are larger still—for example, Atlantic bluefin tuna—have large swim bladders, which usually resonate at frequencies below 100 Hz.

With that information, and knowing a little bit about what kinds of fish live in the area, you can often determine what species you are seeing on sonar. It was from just this kind of consideration, for example, that we realized we were tracking herring and not Peruvian anchovy or Icelandic capelin over Georges Bank in 2006.

This ability makes our sonar system ideal for collecting information about changing fish populations. As Torrence Johnson, a colleague of ours at the Jet Propulsion Laboratory, in Pasadena, Calif., noted, "It's like having Doppler weather radar for fish!" Use of a system this powerful would likely make it far too easy for commercial fishers to decimate fish populations. So a sonar like ours requires strict regulation. Perhaps the most straightforward approach for that would be to enforce existing government-imposed limits on the amount of sound that can be injected into the ocean.

**Water Woofers:** The new source array [top], essentially a string of underwater loudspeakers such as this one [center], was completed after careful testing [bottom] earlier this year.

PHOTOS: MIT LABORATORY FOR UNDERSEA REMOTE SENSING

WITH AN EYE ON THE REGULATIONS THAT use of such sonar equipment would demand, we're moving forward on the development of a next-generation unit. Our first system was an awkward Rube Goldberg device, patched together from spare bits of defunct Cold War hardware. It was cumbersome to operate at sea, requiring two ships, with a large crew of handlers on each. The new system—funded by the National Science Foundation Major Research Instrumentation Program—is half the size, half the weight, and takes just one ship and a handful of people to operate. We expect it to be ready in early 2012.

Many other research tasks await our attention. Some of our primary goals are to study fish species that have great ecological, economic, and societal importance, namely Barents Sea capelin, Alaskan pollack, Peruvian and South African anchovies, Atlantic bluefin tuna, Southern blue whiting, and Argentinian hake. In our own home waters of Massachusetts Bay and the Gulf of Maine, which boast centuries of celebrated fishing history, cod populations have yet to be accurately determined, and we've been asked to help get better counts.

After that, we hope to build on one of our recent theoretical findings: that it should be possible to use a somewhat higher-frequency sonar to image krill in the Southern Ocean. Antarctic krill—shrimplike crustaceans with largely transparent bodies—are vital to the marine food chain and are perhaps the most abundant animal species on the planet. But some scientists worry that they will suffer as the Southern Ocean warms. Our sonar might help determine if these concerns are well founded.

The oceans cover nearly three-quarters of Earth's surface, yet to this day they remain dark and largely unexplored frontiers. By casting some light on the ocean with wide-area sonar, we hope we can help to preserve marine life. Perhaps one day fixed sonar platforms will scan the ocean much as fixed radar stations currently monitor weather and bird migrations on land. If used responsibly—perhaps by delaying the release of the data for a month or two—the information gleaned would provide marine biologists with a valuable scientific resource without compromising the sea creatures it reveals. ❏

TECHNISCHE UNIVERSITÄT DARMSTADT

**The Department of Electrical Engineering and Information Technology invites applications for a position of full**

## Professor (W3) for Power Electronics (Successor of Prof. Mutschler)

(Code. No. 253)

effective April 1, 2012.

The search is for an outstanding candidate who will be responsible for the research and the teaching in the above area. It is also expected that the candidate will conduct a reasonable amount of teaching of foundation subjects.

**Major research areas in the field of power electronics are:**

- Power electronics application in electrical power transmission and distribution (e.g. FACTS, HVDC)
- New compact inverter topologies for automotive applications
- Highly dynamic, low-loss power electronics circuits (e.g. resonant switching, matrix inverters)
- Application of new types of power switches (e.g. silicon carbide technology)
- Improvement of control strategies for power electronics e.g. for drive systems, active power filters, inductive melting, etc.

The candidate will be an authority in at least one of the above research areas and will have proven teaching qualifications. Successful experience in industry or a research organisation is desirable. It is expected that the candidate is prepared to collaborate at a national and international level as well as with groups in one of the priority research areas of the university.

The position is tenured with a remuneration package commensurate with experience and qualifications, following the German "W-Besoldung". The regulations for employment are specified under §§ 61 and 62 HHG (Hessisches Hochschulgesetz).

The Technische Universität Darmstadt intends to increase the number of female faculty members and encourages female candidates to apply. In case of equal qualifications applicants with a degree of disability of at least 50 or equal will be given preference.

Submit applications with the usual attachments and three referee names, quoting the reference number to:
Dean of the Department, Prof. Dr.-Ing. Helmut F. Schlaak, Merckstrasse 25, D-64283 Darmstadt, Germany (dekanat@etit.tudarmstadt.de). For further information contact the Chair of the Search Committee, Prof. Dr.-Ing. Volker Hinrichsen (phone: +49 6151 16 2529, e-mail: hinrichsen@hst.tu-darmstadt.de).

**Application deadline: 15-Sep-2011**

ieee spectrum TECH INSIDERS webinar series

## Where today's technology gurus converge.

The brightest minds discussing the biggest topics.

**Earn CEUs and PDHs by attending a Tech Insider Webinar!**

### UPCOMING AUGUST WEBINAR

**Simulation of Electrodeposition Processes Using COMSOL • 18 August**
Modeling and simulations are cost effective ways of understanding, optimizing, and controlling electrodeposition processes. This webinar introduces you to the simulation of electrochemical deposition, forming, and plating processes. **spectrum.ieee.org/webinar/1886740**

### AVAILABLE ON DEMAND WEBINARS

**Smart-Grid Control Systems: Moving Towards a Self-Healing Grid**
This webinar explains the fundamentals of smart-grid distribution and bidirectional power-control systems. It also provides tips and tricks for developing a control architecture with peer-to-peer communication between distributed nodes and FPGA-to-FPGA control links. **spectrum.ieee.org/webinar/1855445**

**The Insight You Want, the Data You Need: Transforming Insights Into Action**
Join IBM for this webinar to understand how organizations are applying analytics today, prioritizing their future investments, and transforming insights into action. **spectrum.ieee.org/webinar/1856039**

**Model-based Solutions to the Code Maintenance Nightmare — Tackling Key Development Headaches**
Hear from several financial and market-research experts about how organizations can use analytics to plan their future investments. **spectrum.ieee.org/webinar/1868779**

**Acoustics Simulation in Microphones, Mobile Devices and Hearing Aids Using COMSOL**
This webinar discusses simulation of small acoustic devices like microphones, mobile devices or hearing aids, and how it is necessary to include the physics of thermoacoustics. **spectrum.ieee.org/webinar/1849299**

**Real-Time Matters! Timing and Performance Analysis for Embedded Systems**
This webinar will demonstrate on the example of automotive in-vehicle E/E systems — the combined usage of IBM Rational Rhapsody and INCHRON chronSIM real-time simulation tool to achieve measurable quality and cost efficiency with a model-driven simulation approach. **spectrum.ieee.org/webinar/1834882**

SPONSORS: NATIONAL INSTRUMENTS · COMSOL · IBM

IEEE Advancing Technology for Humanity

**Sign up today!**
**www.spectrum.ieee.org/webinar**



ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

ieee spectrum | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Qmags THE WORLD'S NEWSSTAND®

TU WIEN

TECHNISCHE UNIVERSITÄT WIEN

Vienna University of Technology

## Position Announcement:

## Full Professorship in Communication Networks

This is a permanent, senior appointment, and the successful candidate will be expected to teach lectures and seminars (German/English), demonstrate leadership in research in her/his selected area, and to supervise Bachelor, Master and PhD students in electrical engineering and information technology. Scientific work in a leading position at the Telecommunications Research Center Vienna (Forschungszentrum Telekommunikation Wien, ***www.ftw.at***) is possible.

Next generation communication networks will be largely decentralized and the corresponding cross-layer optimization has to consider the current traffic load. To this aim, the terminal nodes will increasingly take over functionalities of the access and core networks. The challenges of network capacity enhancement and the integration of heterogeneous network structures require complex protocols and optimization algorithms based on system and information theory, as well as future technology.

This position shall focus on a selection of the following areas of expertise:

- Network architectures
  - Next Generation IP for access and core networks, Internet of the future
  - Decentralized and centralized network architectures, protocols and algorithms
  - Ultra high speed networks
  - Adhoc networks (Dynamic topology management, route management)
- Error tolerant and self organizing communication networks
- System- and information theory, as well as technology for communication networks
- Virtualisation of networks, resources, protocols and services
- Heterogeneous transport systems
- Content management and content distribution
- Security in communication networks (Identity management, end-to-end security)

The professorship shall focus on the cooperation of network intelligence and performance (algorithmic complexity) in heterogeneous network technologies, encompassing protocols, algorithmic analysis and performance. We thus are seeking an expert who particularly brings in methodology for performance measurements and evaluation, simulation and optimization as well as complexity analysis. All those fields of research are highly popular among the students.

Candidates must have a doctoral degree in a relevant discipline, several years experience in research or teaching in at least one of the above areas, a strong record of publications and attracted research funding, a habilitation degree or equivalent. Candidates are asked to attach to their application those five of their publications they consider to be most significant. Relevant work experience abroad and/or in a non-university setting is desirable. Candidates must have didactic as well as leadership qualifications as required for university teaching and research.

The Vienna University of Technology is an equal-opportunity employer, and selection is based on merit. The University aims to increase the proportion of female staff in leading and researcher positions; applications from females are, therefore, explicitly encouraged. Female applicants are given preference over the best male applicant with the same qualifications, unless reasons that lie in the person of another applicant are seen to outweigh this rule. Disabled persons with suitable qualifications are explicitly encouraged to apply.

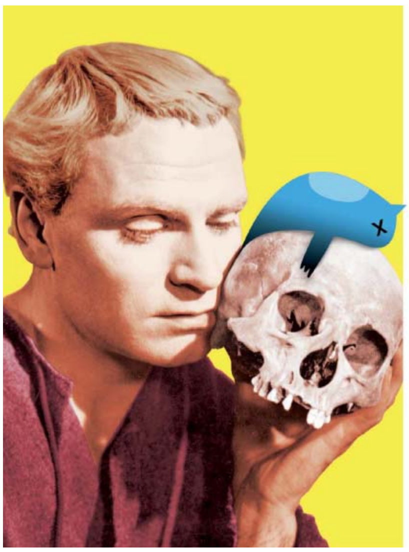
Written applications, including a CV, a description of scientific and professional interests, list of publications, lectures/seminars and a statement on the future development in this area as it pertains to the Technical University, are to be sent to:

**Technische Universität Wien,**
**Fakultät für Elektrotechnik und Informationstechnik**
**Gusshausstrasse 30**
**A-1040 Wien.**

Deadline for receipt of applications is October 28, 2011.

# the data

## Could Shakespeare Have Tweeted *Hamlet*?



TWITTER NOTORIOUSLY limits tweets to 140 characters—the size of an SMS text, minus 20 characters for the tweeter's user name. So what can—and cannot—be said in 140 characters? For example, how does that stack up when it comes to speeches in a play, sentences in a novel, amendments to the U.S. Constitution, or verses in the Bible?

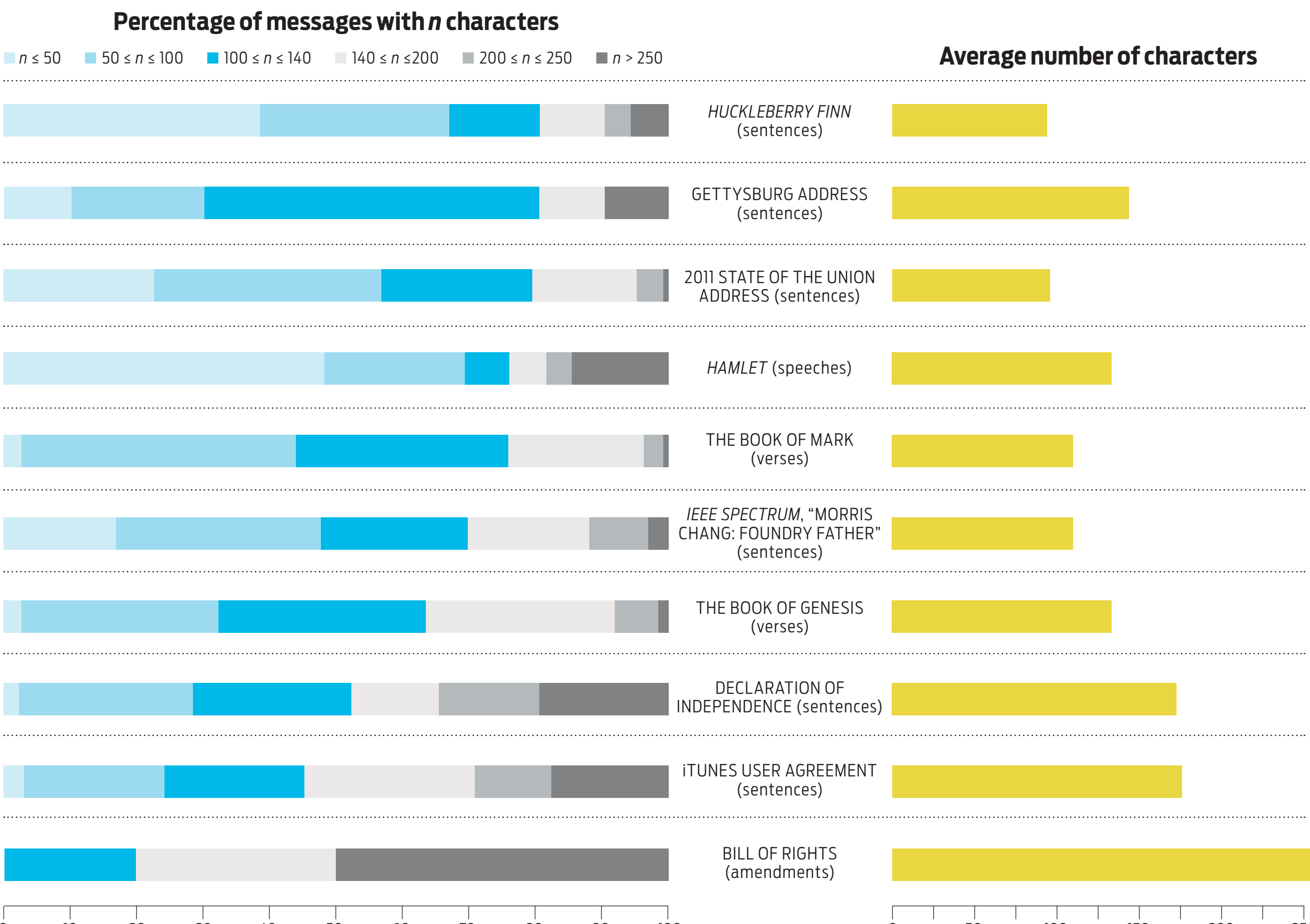
Our calculations show that the Bill of Rights averages 264.6 characters per amendment; only 2 of these first 10 amendments to the Constitution would fit into a tweet. Mark Twain's *Huckleberry Finn* did about as well as any work we looked at, with 94 characters per sentence. Nevertheless, roughly one-fifth of its sentences exceed the 140-character limit. (To be sure, quotes and sentence fragments can be counted in different ways, but the numbers shown here wouldn't change drastically.)

But constraints can be good—they may force a writer to be succinct. Perhaps we at *IEEE Spectrum* could learn something from Huck Finn's biographer: The sentences in our May cover story on Morris Chang averaged 114 characters, with more than a third of them exceeding 140.

"What's important about 140 characters is not the character length but how an accident of history triggered innovative cultural practices," says Danah Boyd, a senior researcher at Microsoft Research. As an example, Boyd cites the shorthand that telegraph users developed because they were charged by the letter. SMS and Twitter users have similarly evolved a shorthand, and there are least 10 different URL shortening services.

So, no, Shakespeare couldn't have tweeted *Hamlet*. But the more relevant question may be: How might the Bard have written differently under this constraint?

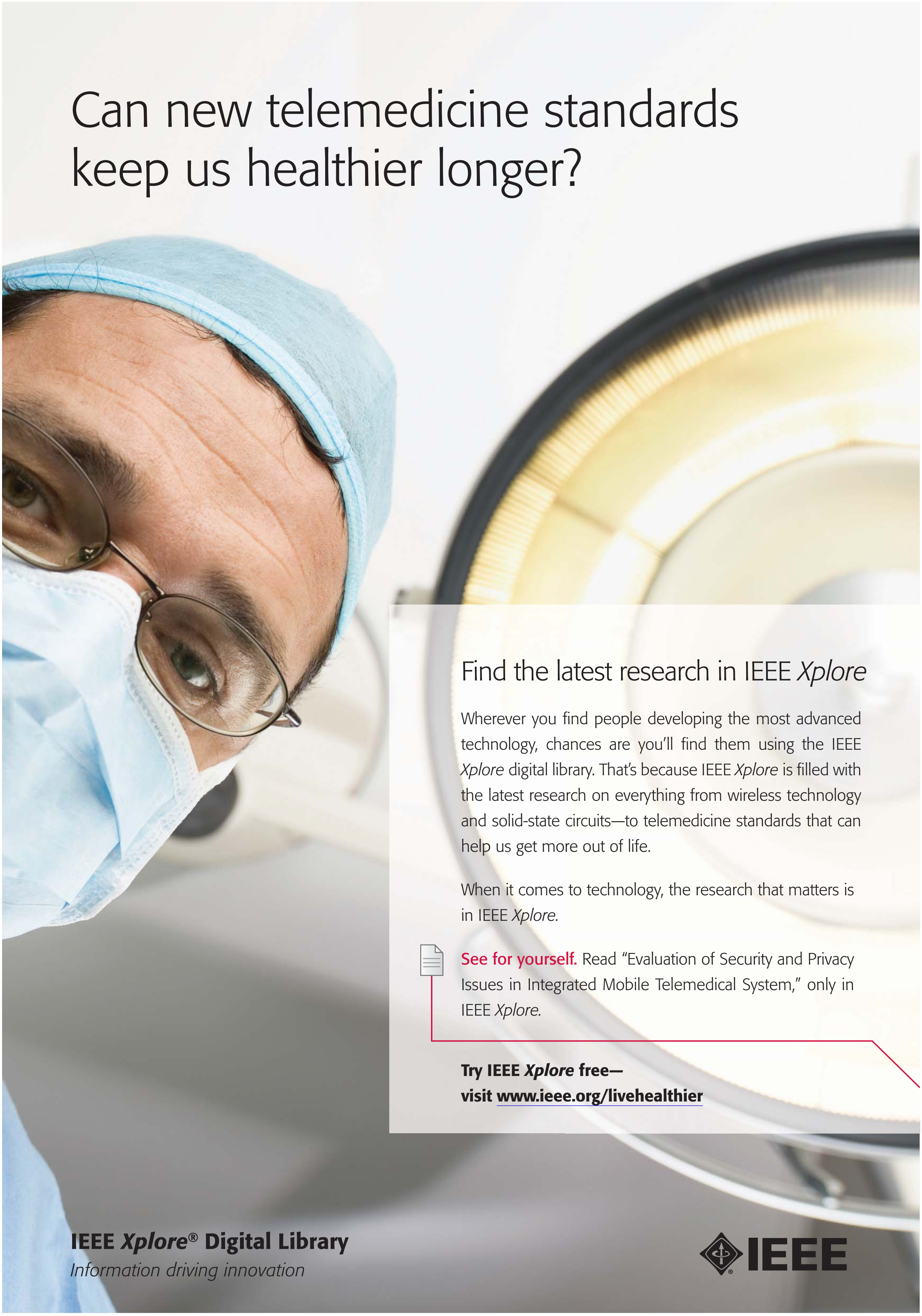
*—Joel B. Predd*

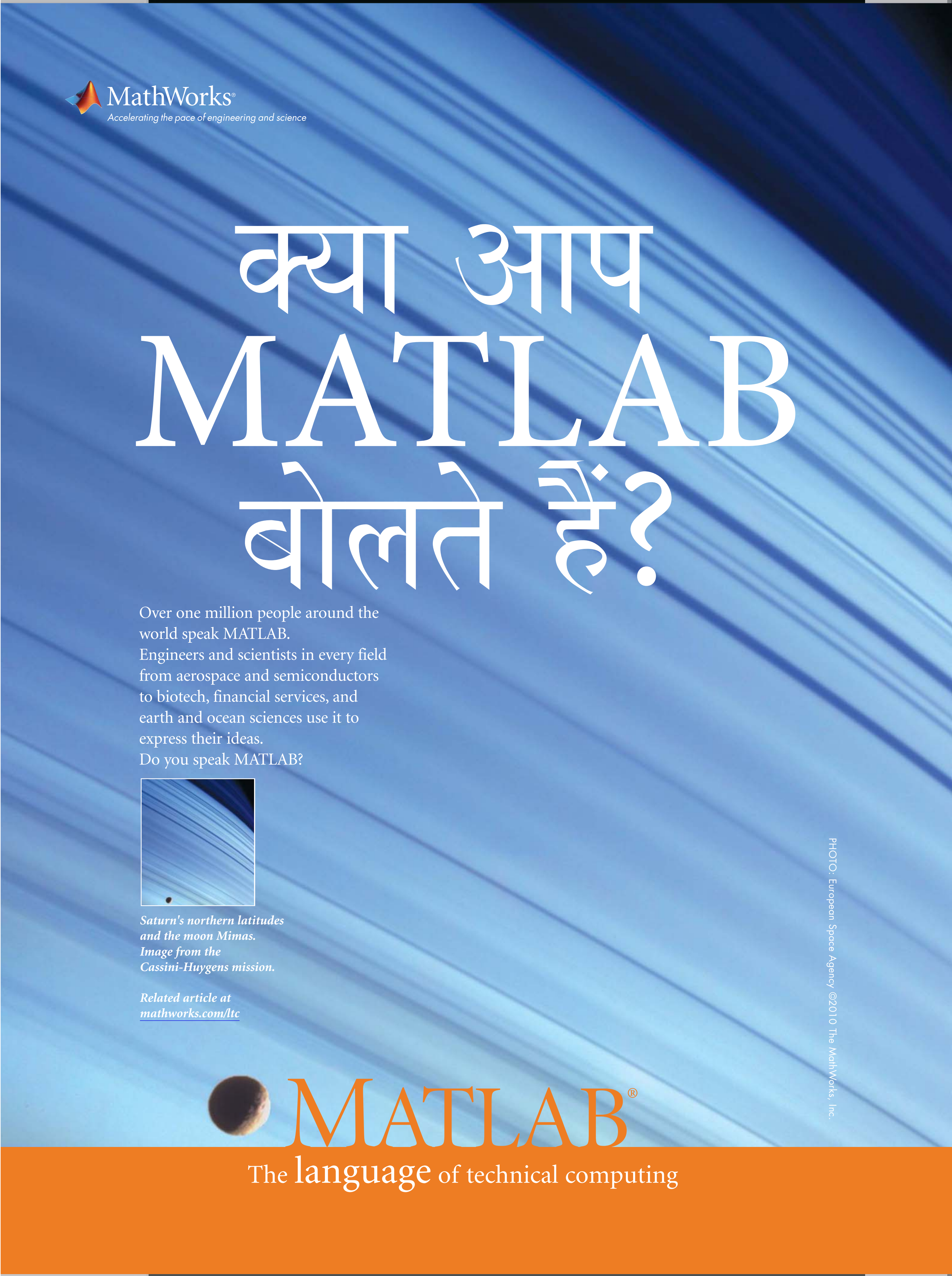



SOURCE: JOEL B. PREDD; PHOTO-ILLUSTRATION: GLUEKIT; PHOTO: ALAMY



ieee spectrum Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Qmags THE WORLD'S NEWSSTAND®


Can new telemedicine standards keep us healthier longer?
Find the latest research in IEEE Xplore
Wherever you find people developing the most advanced technology, chances are you'll find them using the IEEE Xplore digital library. That's because IEEE Xplore is filled with the latest research on everything from wireless technology and solid-state circuits—to telemedicine standards that can help us get more out of life.
When it comes to technology, the research that matters is in IEEE Xplore.
See for yourself. Read "Evaluation of Security and Privacy Issues in Integrated Mobile Telemedical System," only in IEEE Xplore.
Try IEEE Xplore free—
visit www.ieee.org/livehealthier
IEEE Xplore® Digital Library
Information driving innovation
IEEE


MathWorks®
Accelerating the pace of engineering and science
क्या आप MATLAB बोलते हैं?
Over one million people around the world speak MATLAB.
Engineers and scientists in every field from aerospace and semiconductors to biotech, financial services, and earth and ocean sciences use it to express their ideas.
Do you speak MATLAB?
Saturn's northern latitudes and the moon Mimas. Image from the Cassini-Huygens mission.
Related article at mathworks.com/ltc
PHOTO: European Space Agency ©2010 The MathWorks, Inc.
MATLAB®
The language of technical computing