10 World Changing Ideas

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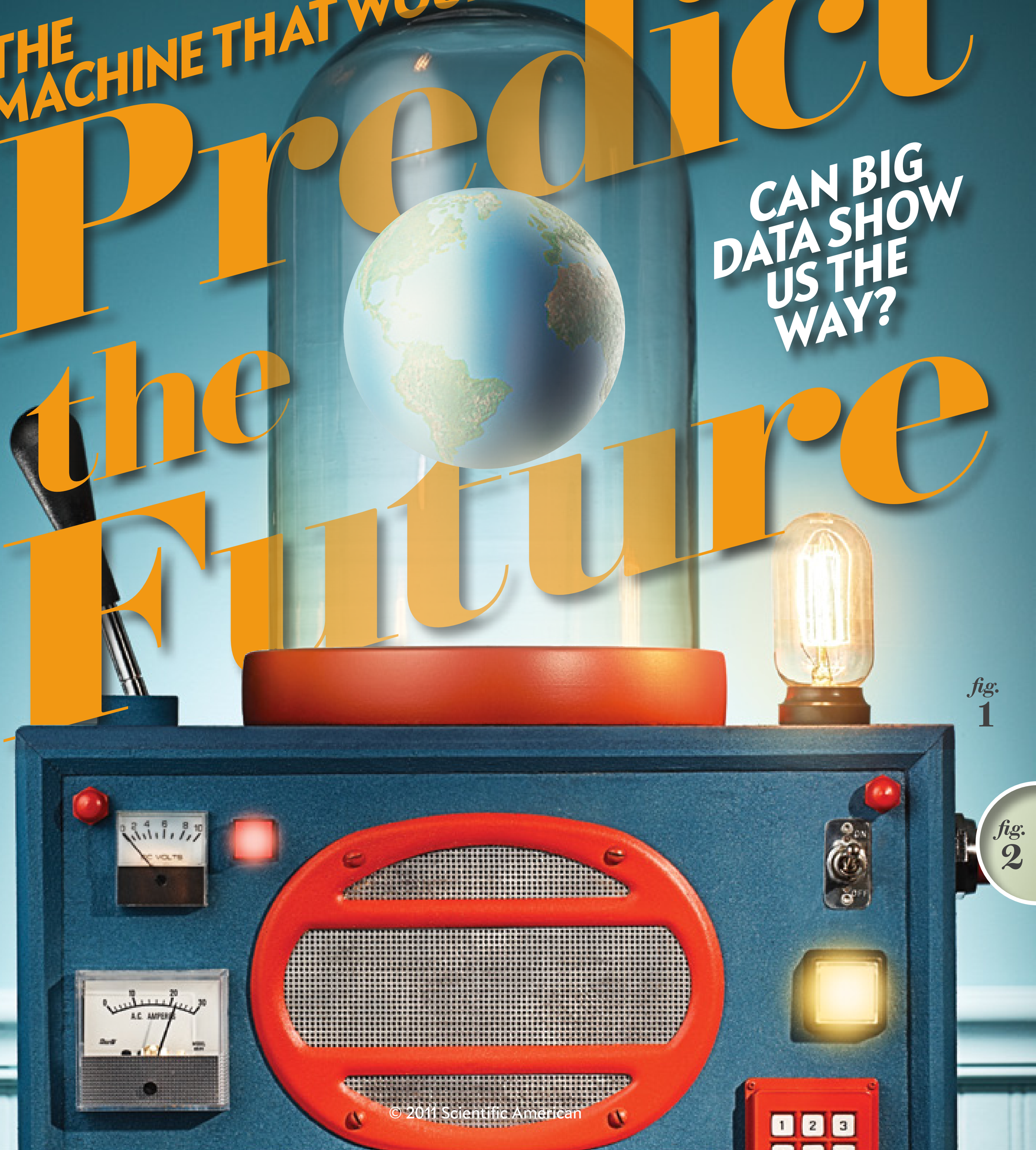
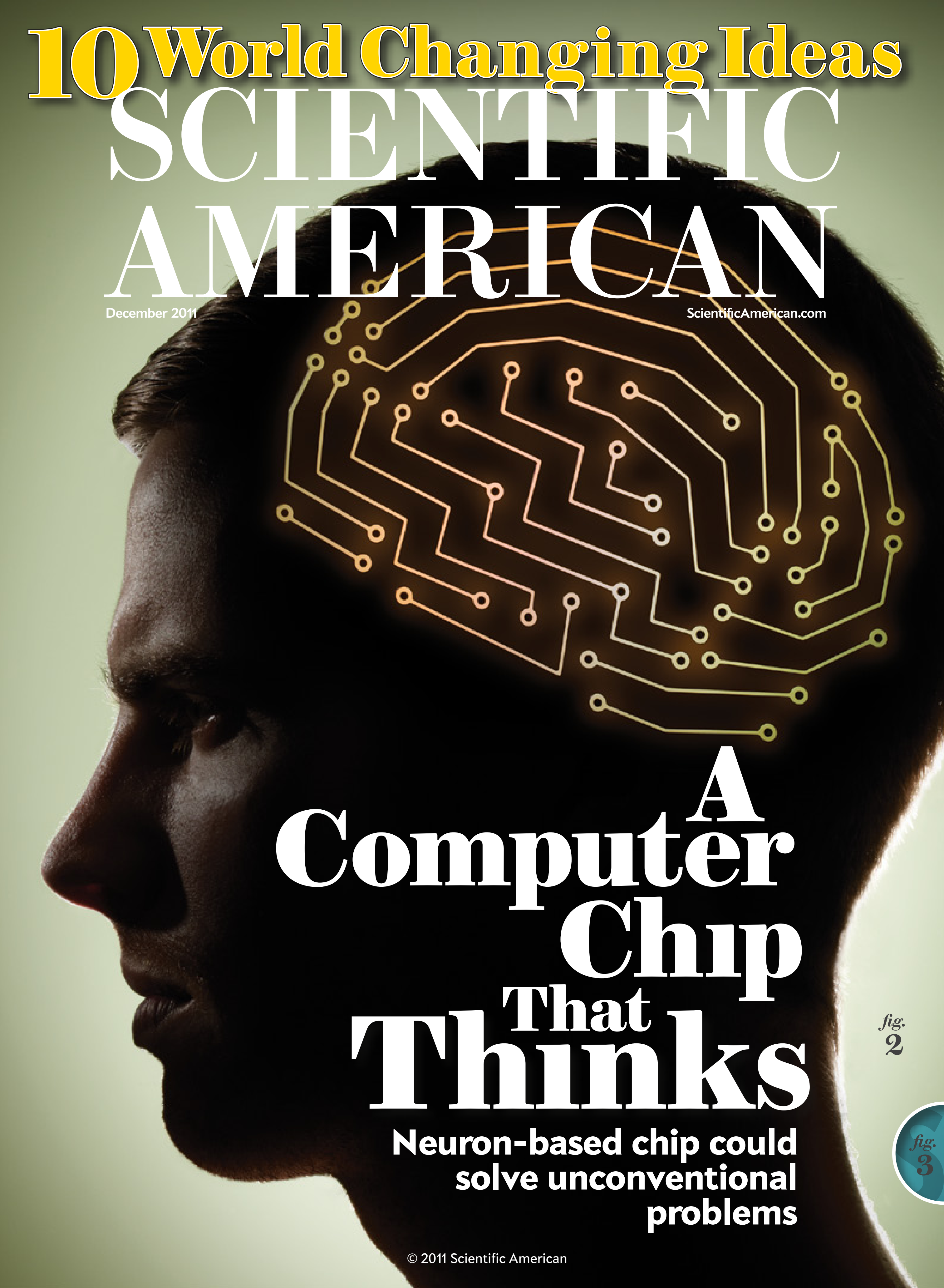
THE MACHINE THAT WOULD Predict the Future

CAN BIG DATA SHOW US THE WAY?





10 World Changing Ideas

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A Computer Chip That Thinks

Neuron-based chip could solve unconventional problems

fig. 2

fig. 3


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10 World Changing Ideas

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PERENNIAL CROPS

I.D. IN YOUR HAND

NANOTECH ANTIBIOTICS

PERMANENT HEALTH MONITORS

LIQUID-FUELED ELECTRIC CARS

SELF-AWARE CIRCUITS

E-MONEY

MICROBE MINERS

fig. 3


SEE THE
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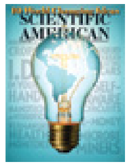
BEHIND THE
SOLUTION

SCIENTIFIC AMERICAN

December 2011 Volume 305, Number 6

ON THE COVER



Our third annual "World Changing Ideas" special issue showcases 10 technologies and trends that will shape the future. In addition to stories on neural microchips, crypto-currencies and nanotech antibiotics, we take a close look at an ambitious project to exploit the growing torrent of available data streams to model politics, culture, finance and the environment. Photographs by Dan Saelinger.

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Piscine profile: A live baby trout, in the second of the fish's four life stages, poses under a stereomicroscope for Canadian Robert Berdan, one of the photographers in the 2011 Olympus BioScapes competition.

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Sending people to asteroids and beyond would be affordable if engineers adapted ideas of their colleagues who make robotic planetary probes.
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Innovation starts with the courage to imagine.


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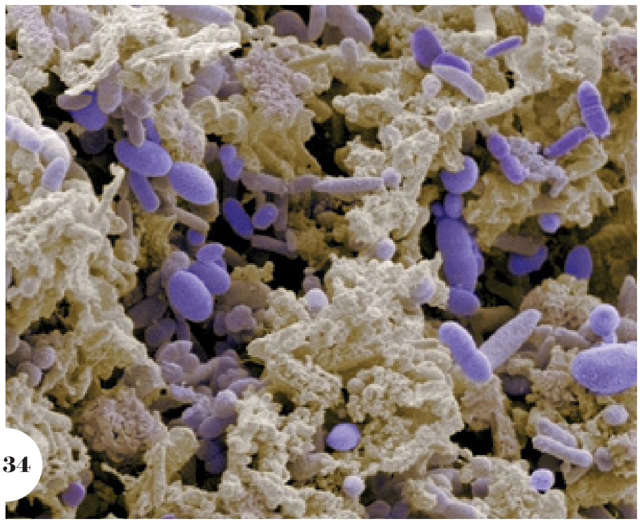
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ON THE WEB

Where to for NASA?
In conjunction with the article in this issue by Damon Landau and Nathan J. Strange, outlining a bold new proposal for manned interplanetary exploration, we look at what NASA's future holds—and what could have been.
Go to www.ScientificAmerican.com/dec2011/deep-space

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Mariette DiChristina is editor in chief of *Scientific American.* Find her on Twitter @mdichristina

Emergent Genius

WHERE DO GREAT IDEAS come from—and how do we recognize their significance when they appear?

Danny Hillis, Applied Minds co-founder and a *Scientific American* adviser, and I were discussing these questions recently as we prepared for a talk in late October at the Compass Summit (compass-summit.com). "Ideas are a product of society," an emergent phenomenon, Hillis told me, "which are almost inevitable." That's why, he said, our admiration for individuals who have come up with such ideas is "almost giving too much credit." The idea itself is not enough. A lot of people in a society will have a given notion, he explained. Maybe only 1,000 will try to sketch it out. "Then 100 will try to make something, and 10 of those might actually make something practical. One or two of those might be on the level of an Edison or Tesla."

In many ways, Hillis and I share a mission of identifying those ideas that just might work. His company, of course, is involved in developing them. As for the magazine and our Web site's role? "The interesting thing about *Scientific American* is it lets you *understand* those ideas," he added.

We have both watched with interest recent sweeping trends in the idea machine: how interdisciplinary research is a growing area of focus and the rising force of "big data" and increasing computing power. Those topics would be part of our on-stage Compass Summit conversation, and they also underpin this issue's special look at innovation, the third annual "World Changing Ideas," starting on page 40. The section features 10 out-of-the-lab concepts with the possibility to scale in a practical way.

I'm particularly taken by "The Machine That Would Predict the Future," by David Weinberger, starting on page 52. The story covers the work of Dirk Helbing, a physicist and chair of sociology at the Swiss Federal Institute of Technology Zurich. Helbing has proposed a large-scale computing program that would attempt to model global-scale systems and so "would effectively serve as the world's crystal ball."

Perhaps you, like me, will feel forcefully reminded of Isaac Asimov's Hari Seldon, the "psychohistorian" whose pattern-predicting math drove the famous Foundation science-fiction series. Asimov, a long-time *Scientific American* subscriber himself, read the magazine to keep up with science. Increasingly, it feels as if the reverse is also true. SA

Photograph by Dan Saelinger; Illustration by Nick Higgins

editors@sciam.com

August 2011

WHY CRIME DROPPED

In "How New York Beat Crime," Franklin E. Zimring refers only incidentally to a decline since 1990 in the "percentage of the population in the most arrest-prone bracket, between 15 and 29," in both New York and the nation. The nationwide decline in that age group must be a contributing factor to the crime drop in that city and the U.S. as a whole. The book *Freakonomics,* by Steven D. Levitt and Stephen J. Dubner, attributes the nationwide decline in crime to the 1973 U.S. Supreme Court decision in *Roe v. Wade* to legalize abortion. The logic is that as more unwanted pregnancies are terminated, fewer unwanted (and unloved) children are born, so fewer will grow up to be criminals. And the timing is perfect for the decline in the arrest-prone age bracket.

STEVEN STONE
Cupertino, Calif.

Zimring's analysis of the period of the New York City crime drop was excellent but failed to refer to what came before. As a result of the 1970 Knapp Commission investigation into police corruption in the city, the New York Police Department instituted rules and policies designed to stamp out corruption that had the unintended effect of encouraging an uncommonly docile police force. This docility continued through the 1990s until the appointment of William J. Bratton as police commissioner. The Bratton-led department ushered in novel changes in tactics and policies as well as raising the level of aggressive policing in the rank and file.

"Editors of scientific journals should employ 'results blind' decision making in determining whether to publish."

JOSEPH J. LOCASCIO *HARVARD MEDICAL SCHOOL*

BOB VIALIZ
Mahopac, N.Y.

Near the end of Zimring's article, he mentions that even New York City's much reduced homicide rate is far higher than that of most major European cities and Tokyo. He suggests that New York must address social issues to further reduce its crime rate but seems to ignore a major pachyderm in the parlor: namely, that in these foreign nations gun ownership is far smaller.

GEORGE SCHUTTINGER
Mountain View, Calif.

ZIMRING REPLIES: The famous theory that Roe v. Wade *reduced U.S. crime in the 1990s that Stone refers to is discussed in my book* The Great American Crime Decline *(Oxford University Press, 2008). I am skeptical about the decision having a major impact on nationwide U.S. crime in the 1990s because it did not strongly affect the births of children considered to be at high risk of becoming criminals.*

But a major influence from legalized abortion on the New York City difference is particularly implausible for three further reasons: First, what separates New York from other cities is a decline from 2000 to 2007. Why should the effects of legalization last longer in Gotham? Second, crime in New York State's other cities did not follow the New York City trend, yet abortion is a function of state law. Last, the same situational and contingent features of crime that explain police effectiveness in stopping it argue against the deterministic view that one generation's births will control the volume of the next generation's crime.

Vializ's logic that policing after 1990 had such powerful effects in New York in part because the police were not very effective before 1990 is impeccable. But because we do not know whether the aggression of more recent efforts added value to strategies such as hotspots, there is no way to test the contribution of unaggressive prior efforts to the larger marginal changes over time.

Finally, Schuttinger is no doubt correct that handgun use inflates the rate of American homicide. All the more remarkable, then, is the more than 80 percent drop in New York City killings despite this handicap.

BIGGER BORDER

It has been my understanding for a while that the radius of the observable universe is roughly 13.7 billion light-years. Yet the box entitled "What Lies Beyond?" in "Does the Multiverse Really Exist?" by George F. R. Ellis, says that astronomers see out to a distance of about 42 billion light-years, our cosmic horizon.

How can light travel more than 13.7 billion light-years in 13.7 billion years?

WILLIAM B. KEITH
Houston

THE EDITORS REPLY: Space is expanding, carrying objects such as galaxies and photons with it, so light travels a greater distance than a simple calculation (such as speed multiplied by time) might suggest. An object that emitted light 13.7 billion years ago is now 42 billion light-years away. This figure depends on the values of cosmological parameters.

STATISTICAL SUGGESTION

As a biostatistician, I concur with Charles Seife's critical comments about the abuses of the so-called *p*-value as a measure of statistical significance of data in "The Mind-Reading Salmon" [Advances]. Statisticians have criticized this methodology before, sometimes even recommending banning it. I would temper such criticism, however, by pointing out that there are a variety of adjustments to *p*-values to take into account the kind of multiple-testing artifact Seife refers to, and they are often used (though perhaps not as much as they should be).

Another issue relevant to this topic is the publication bias of many journals,

Clair Field, North Sea, UK

which often give greater weight toward publishing articles that report statistically significant findings over those that don't. I have advocated before that one way to mitigate problems with null-hypothesis significance testing is for editors of scientific journals to employ "results blind" decision making in determining whether to publish and make it be known that they are doing so. Articles should be accepted for publication based primarily on the judged importance and relevance of the reported study, which is usually stated and defended in the "introduction" section of the manuscript, and whether the methodology (including that of the data analysis) is sound, which can be assessed via the "methods" section of the manuscript.

With this kind of review process, if 20 studies of the effectiveness of a truly ineffective drug are conducted, and one of them shows a significant effect with a *p*-value of 0.05 because of chance alone, investigators for the other 19 studies not showing any effect would presumably not be inhibited from writing up and submitting reports of these for publication out of fear that they'll be denied publication because of their nonsignificant results. Publishing of those results would then cause the scientific audience to be rightly skeptical of the one significant finding amid the many reports not demonstrating it.

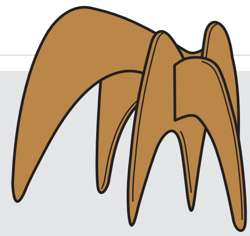
Joseph J. Locascio
Instructor in Neurology
Harvard Medical School

CLARIFICATION

"Bombarded," by Mark Fischetti [Graphic Science], states that the intensity of exposure to electromagnetic radiation "is proportional to distance." It should have read that exposure "varies with distance." Intensity is inversely proportional to the square of distance.

ERRATUM

"The False Promise of Biofuels," by David Biello, states that all the energy in crops, plants consumed by livestock, and trees harvested for pulp, paper and other wood products comes to about "180 exajoules, or about 20 percent of world consumption." The text should have said, "180 exajoules, or about a third of present world consumption."



Winner of the 2011 National Magazine Award for General Excellence

LETTERS TO THE EDITOR

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at ScientificAmerican.com/dec2011

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Accelerating Software Modernization
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AI is radically transforming the way organizations evolve their software assets to achieve competitive advantage.

Artificial Intelligence (AI) is the quest to achieve computers that equal or exceed human performance on complex intellectual tasks. A phenomenal development in AI is the recent emergence of automated computer language translation programs, driven by the need to modernize the nearly half trillion lines of legacy software developed during the latter half of the 20th century.

Just as chess programs routinely outperform grandmasters, leveraging AI technologies that evolved from the 1980s-era USAF's Knowledge-Based Software Assistant Program and emerging standards, computers can now understand and translate software applications with levels of proficiency that vastly exceed human performance. This technology is revolutionizing the way industries, such as finance, insurance, manufacturing, and healthcare, as well as military and governments, are modernizing their legacy systems.

Leading this field is The Software Revolution, Inc. (TSRI), a Kirkland, Washington-based company. Building upon 32 years of continuous R&D, TSRI's robust *JANUS* Studio® tool suite provides large-scale, error-free legacy system modernizations at 100% levels of automation. By applying AI to abstract software models, TSRI delivers automated code conversion with unprecedented target code quality, economies of scale, and schedule compression, accomplishing with small teams in months what would take years by other means. The following list of brief case studies represents five recent TSRI legacy system modernization projects.

European Air Traffic Management System (EATMS), Thales Air Systems: This real-time system manages over 100 million passenger flights annually. Thales engaged TSRI to transform EUROCAT's 2 million lines of legacy Ada into Java. On Monday, April 18th, 2011, the system went online for Air Traffic Control (ATC) use at the Shannon Center, in Ireland. This marked a milestone that is expected to lead to the use of the modernized ATC system at the 280 airports in Europe, Asia and Australia, where EUROCAT is currently in use. TSRI's 100% automation eliminated the risk of a manual rewrite of this safety-critical system.

Patriot Missile, Fire Platoon Simulation & Battalion Simulation Support Systems, Raytheon: TSRI used the *JANUS* Studio® tool suite to modernize four different Patriot systems, including Patriot Japan. These modernizations included the transformation of nearly 200 thousand source lines of Fortran code to C++, re-factoring and documentation.

Major Healthcare Insurance Company: This system consisted of over 180 thousand source lines of PowerBuilder and nearly 3 million lines of COBOL. In modernizing this system, TSRI provided transformation and re-factoring, and supported system integration. This project was completed in only 15 months.

Major US Bank: This legacy application contained over 3 million source lines of Fortran and over 160 thousand lines of DCL. TSRI automatically generated a *Transformation Blueprint*® to assist in the system's design architecture, performed the code documentation, and provided engineering support.

Advanced Field Artillery Tactical Data System (AFATDS), Stanley and Associates (Now CGI Federal): This system consisted of over 5 million source lines of ADA-83. TSRI employed the *JANUS* Studio® tool suite to transform this system into Java in only 10 months. TSRI delivered the modern system to Stanley in August 2010.

The book, **Information Systems Transformation: Architecture-Driven Modernization Case Studies**, referenced below, provides more detailed information on some of these case studies.

For more information, visit **www.tsri.com**.

Information Systems Transformation:
Architecture-Driven Modernization Case Studies
By William M. Ulrich and Philip Newcomb
ISBN: 978-0123749130

About the book:
Architecture-Driven Modernization (ADM) gives you everything you need to know on updating costly obsolete systems, transform data, and save millions of dollars.

Philip Newcomb
Founder and CEO of TSRI

Mr. Newcomb, the 2011 recipient of the Stevens Award, is an internationally recognized expert on the application of AI and formal methods to software modernization. At TSRI he leads a team of scientists who created *JANUS* Studio®, the world's leading automated software transformation tool. He is the author of many publications and a leading contributor to the OMG's ASTM, SMM and IPMSS standards.

TSRI is a Platform Member of the OMG and leading contributor to the ADM Task Force (ADMTF) standards. TSRI's services and its *JANUS* Studio® tool suite have served as the leading exemplar for the OMG's emerging ADMTF standards.


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Opinion and analysis from *Scientific American*'s Board of Editors

Stop the Genetic Dragnet

Police currently collect samples of DNA from detainees—retaining the DNA even if a suspect turns out to be innocent

In 2009 the San Francisco police arrested Lily Haskell when she allegedly attempted to come to the aid of a companion who had already been taken into custody during a peace demonstration. The authorities released her quickly, without pressing charges. But a little piece of Haskell remained behind in their database.

Haskell is one of hundreds of thousands who have had their DNA extracted as part of an enormous expansion of what were once categorized as criminal data banks. Police in about 25 states and federal agents are now empowered to take a DNA sample after arresting, and before charging, someone. This practice occurs even though many of those in custody are never found guilty. If they are cleared, their DNA stays downtown, and they must undergo a cumbersome procedure to clear their genetic records.

Courts nationwide are now wrestling with the civil-liberties implications. Some have held that the practice violates the Fourth Amendment protection against "unreasonable searches and seizures." Other courts, including one that heard a legal challenge brought by Haskell, have agreed with law-enforcement officials that lifting DNA is no different from taking a fingerprint, an established routine even for those not convicted. Ultimately the U.S. Supreme Court will probably decide this matter.

The ability of DNA technologies to match a tiny sliver of tissue left at a crime scene to a suspect gives them an undeniable allure to law enforcement. For critics, the unreasonableness of this "search" relates to the information-rich nature of DNA. It does more than just ID people. It also has the potential to furnish details about appearance, disease risk and behavioral traits. The laws establishing DNA databases attempt to guard privacy by limiting inspection to only 13 relatively short stretches of DNA among the billions of "letters" of code that make up the genome. Yet that protection may not be enough. Once those 13 markers are extracted, law-enforcement agencies continue to store the larger biological sample. Civil-liberties organizations worry that officials may eventually mine these samples for personal details or make them available for medical research without consent.

New genetic technologies are opening up possibilities that did not arise when the samples were first collected. For instance, a technique called familial searching can match DNA from the crime to someone in the database who is not a suspect but possibly a close relative of one—the database hit would be a near but not identical match to the DNA at the crime scene. The police would then have a whole new set of potential leads who would come under scrutiny as possible perps.

Although this process may nab criminals who would otherwise elude capture, it may also ensnare the innocent. Most of the possible leads produced by searches in partial database matches will have done nothing wrong. These persons of interest are likely to be concentrated in minority communities whose denizens represent a disproportionate fraction of the databases. Moreover, the seeming infallibility of DNA may prompt police to place too much reliance on familial search methods instead of considering nongenetic evidence that may steer an investigation toward other leads, notes New York University School of Law professor Erin Murphy.

The need is acute for legislative safeguards that protect privacy while also allowing police to solve crimes using these powerful tools. DNA samples should not be taken until a suspect is convicted, and even then the original DNA sample should be destroyed once the relevant markers are in the computer to guard against any future temptation to delve into someone's private life. Finally, familial searches should be undertaken only as a last resort after other investigative leads have been tried—an approach that California has adopted and that other states should follow.

DNA is not just a technological progression from fingerprinting. It is qualitatively different. As such, it needs to be treated as more than a mere formality of a police booking procedure. ■

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Illustration by Edel Rodriguez

Commentary on science in the news from the experts

Edward T. Lu is a former NASA astronaut and chair of the B612 Foundation, a nonprofit group that is developing programs to detect and deflect asteroids. From 2007 to 2010 he was manager of Advanced Projects at Google.

Stop the Killer Rocks

The job of saving humanity from extinction currently falls to no one. NASA and other organizations should take it on

Asteroid Eros

COURTESY OF NASA/GODDARD SPACE FLIGHT CENTER'S SCIENTIFIC VISUALIZATION STUDIO

Over the past couple of years the U.S. space program has gone through a huge shake-up, leaving the nation's goals in space unclear. I have a suggestion. NASA, working with other national space agencies and private organizations, should take on the job of ensuring that no destructive asteroid ever hits Earth on our watch. What project is more worthwhile in the long term or awe-inspiring in the short term than protecting humanity from ruin?

At first glance, asteroids may seem like a distant threat. But the hazard is well documented, and the consequences could not be more severe. The history of life on Earth has been shaped by asteroid impacts. One million of them wider than 40 meters in diameter orbit the sun in our vicinity, by some estimates. An asteroid of that size struck Earth over Siberia in 1908 and laid waste an area 150 times larger than the Hiroshima atomic bomb did. The odds of a repeat in this century are about 50 percent. On the larger end, asteroids greater than about one kilometer across would have global effects that threaten human civilization.

The first step in prevention is prediction. We must find, track and predict the future trajectory of those million near-Earth objects. Astronomers have already catalogued the orbits of most of the kilometer-scale objects they think are out there, and none are known that will hit Earth in the next 100 years. Yet the great majority of smaller ones, those big enough to destroy a country or unleash a tsunami that devastates coastal cities, remain untracked. This unfinished business should be tackled next.

Asteroids are warmer than the background sky and therefore stand out in the infrared. Telescopes have blind spots, however: they cannot look in the direction of the sun, which limits the effectiveness of telescopes stationed on or near Earth. The National Research Council recommended in 2009 that NASA place an infrared survey spacecraft in a Venus-like orbit around the sun. As it looked outward, away from the sun, the observatory would spot asteroids that go unseen from Earth. Once completed, such a survey would remain valid for about a century—the timescale on which the measured orbits begin to change because of gravitational interactions with planets—before we would have to do it again. The cost of such a mission would be several hundred million dollars—expensive, to be sure, but a bargain compared with NASA's current budget, let alone the damage of an asteroid strike.

Should astronomers find an asteroid on a collision course, our task would be to reach out and alter its orbit to prevent that impact. If we find the asteroid early enough (decades ahead of its projected impact), several existing technologies might work: tow it, ram it, nuke it or employ some combination. (My colleagues and I used to advocate pushing on the asteroid with a rocket [see "The Asteroid Tugboat," by Russell L. Schweickart, Edward T. Lu, Piet Hut and Clark R. Chapman; Scientific American, November 2003], but recent results on asteroid properties and orbits have made us reconsider.)

Yet no one is really sure whether these options would actually work. Surely the time to test them is before they are needed for real. NASA and other organizations should build and try out a system to deflect a nonthreatening asteroid in a controllable way. Given that astronomers have not even begun a complete asteroid survey, there is a real risk they will find an incoming asteroid before we have time to do a dry run. So this work must begin now. It would not take large increases to NASA's budget.

All civilizations that inhabit planetary systems must eventually deal with the asteroid threat, or they will go the way of the dinosaurs. We need to predict in advance when impacts are going to occur and, if necessary, shift the orbits of threatening asteroids. In effect, we must change the evolution of the solar system. SA

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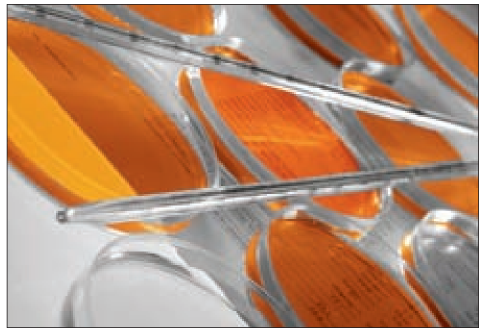

Malaysian biotechnology attracting investors from east and west

During a recent interview I had with Dr. Nazlee, he was able to give me a clear picture as well as a realistic assessment on where Malaysia is headed with respect to Biotech. Dr Nazlee after all is an academician, scientist, innovator and entrepreneur and was recently appointed to head the lead developmental agency for biotechnology in Malaysia – Malaysian Biotechnology Corporation (BiotechCorp).

There are three implementation phases in the National Biotechnology Policy (NBP). The first phase from 2005 to 2010 was for capacity building. At present, Malaysia is in the second phase (2011 to 2015) and this will be for commercialization or "science to market." The third phase from 2016 to 2020 will focus on globalization.

Dr. Nazlee stated "that the success we enjoyed under the first phase of the NBP provided us with a solid foundation from which to work on. We will grow the momentum as we move forward into the *commercialization* phase. The ecosystem we created for the development of the industry under Phase 1, will start bearing fruit."

Foreign investors identify with the hard and soft infrastructure that Malaysia has put in place, and the ecosystem that it has created. The BioNexus program packaged with a set of competitive incentives creates an enabling environment for both foreign as well domestic investors. To date the BioNexus program has a total of 204 companies under its wings, 28% of which involve foreign shareholding.

In supporting the infrastructure and ecosystem for the biotechnology industry, the Government of Malaysia has completed the setting-up of the National Institutes of Biotechnology; namely the Malaysian Genome Institute, The Institute of Pharmaceuticals and Nutraceuticals and the Agri-biotechnology Institute. This is part of the government's firm commitment in providing both world class infrastructure as well opportunities for cutting-edge research to support the growing industries.

Malaysia has also risen in terms of its competitive position in the global market. A report by the World Economic Forum on global competitiveness ranks Malaysia in 21st position, which sets a strong base and is essential in projecting Malaysia in the global marketplace.

In our Worldview Scorecard (published in June 2011), Malaysia ranks third in the world for the best enterprise support of its biotech industry. The country hosts a business friendly environment and significant venture capital availability. With strong scores for enterprise support, Malaysia is a biotech hub where industries thrive with access to a broad collection of business resources.

Apart from manufacturing expertise, Malaysia is a cost effective destination for global companies to expand into bio-processing and bio-manufacturing. LPG, petrol and diesel rates in Malaysia are among the cheapest in the world, industrial electricity and water rates are regionally competitive and average sewage tariffs are the cheapest in South East Asia.

In terms of investment, there are two recent significant projects that BiotechCorp has secured: the RM 2 billion CJ Arkema project for the construction of the world's first bio-methionine plant and Asia's first thiochemical platform in Kertih Polymer Park in Terengganu, within the East Coast Economic Region (ECER). This project is the largest investment in the biotechnology sector for Malaysia to-date.

Another significant investment was from India's Biocon, the largest project in the healthcare sector, which will see the commencement of a RM500 million biopharmaceutical manufacturing and R & D plant in Bio-XCell, Malaysia's first dedicated biotechnology park and ecosystem in Iskandar Malaysia, Johor. To date Bio-XCell has managed to attract more than RM750 million (USD241 million) of investment from India, France and US.

When asked about what are the pull factors attracting investment here Dr Nazlee responded by citing remarks from potential investors such as "very impressed with the infrastructure" and "a perfect location in the middle of Asia which can act as a corridor to emerging markets." He went on to cite "a high level of education and political stability," as equally important.

Nazlee was very bullish on the strict IP laws in Malaysia, noting that he had seen the law in action when violations had been committed.

"We are optimistic that things will turn out well. With the incentives provided by the government for the biotechnology sector and given Malaysia's resources such as manpower and water supply, we are confident of meeting our targets," he added.

Perhaps nothing says it better than Biocon's chairman Kiran Mazumdar-Sha with her endorsement of Malaysia: "In short, Malaysia, with its business friendly environment, was too good to resist."

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Macaque monkey

JANA LEON *Getty Images*

NEUROSCIENCE

Can't Touch This Feeling

Primates can now move and sense the textures of objects using only their thoughts

When real brains operate in the real world, it's a two-way street. Electrical activity in the brain's motor cortex speeds down the spinal cord to the part of the body to be moved; tactile sensations from the skin simultaneously zip through the spinal cord and into the brain's somatosensory cortex. The two actions are virtually inseparable: absent the feel of a floor under your feet, it's awfully difficult to walk properly, and lacking the tactile sensation of a coffee mug, your brain cannot sense how tightly your fingers should grasp it. Until now, attempts to help paralyzed patients move a prosthetic have addressed only half of our interaction with the world. A new study offers hope of expanding that capacity.

Scientists led by Miguel Nicolelis, professor of neurobiology at Duke University Medical Center, have reported the first-ever demonstration in which a primate brain not only moved a "virtual body" (an avatar hand on a computer screen) but also received electric signals encoding the feel of virtual objects the avatar touched—and did so clearly enough to texturally distinguish the objects. If the technology, detailed in the journal *Nature,* works in people, it would change the lives of paralyzed patients. (*Scientific American* is part of Nature Publishing Group.) They would not only be able to walk and move their arms and hands, Nicolelis says, but also to feel the texture of objects they hold or touch and to sense the terrain they tread on.

Other research groups are working on similar advances. At the University of Pittsburgh, neuroscientists led by Andrew Schwartz have begun recruiting patients paralyzed by spinal cord injury into a similar trial that would allow them to "feel" the environment around them thanks to electrodes in the somatosensory cortex that receive information from a robot arm.

Nicolelis hopes to bring his research to fruition by 2014, when he plans to unveil the first "wearable robot" at the opening game of soccer's World Cup in his home country of Brazil. Think *Iron Man,* a full-body, exoskeletonlike prosthetic. Its interface will be controlled by neural implants that capture signals from the motor cortex to move legs, hands, fingers and everything else. And it will be studded with sensors that relay tactile information about the outside world to the somatosensory cortex. Buoyed by the advances so far, Nicolelis predicts that the device will be ready in time. "It's our moon shot," he says. —*Sharon Begley*

FURTHER READINGS AND CITATIONS ScientificAmerican.com/dec2011/advances


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FOOD

Microwaves and the Speed of Light

New physics tricks for the most underestimated of kitchen appliances

You can find a microwave oven in nearly any American kitchen—indeed, it is the one truly modern cooking tool that is commonly at hand—yet these versatile gadgets are woefully underestimated. Few see any culinary action more sophisticated than reheating leftovers or popping popcorn. That is a shame because a microwave oven, when used properly, can cook certain kinds of food perfectly, every time. You can even use it to calculate a fundamental physical constant of the universe. Try that with a gas burner.

To get the most out of your microwave, it helps to understand that it cooks with light waves, much like a grill does, except that the light waves are almost five inches (12.2 centimeters) from peak to peak—a good bit longer in wavelength than the infrared rays that coals put out. The microwaves are tuned to a frequency (2.45 gigahertz, usually) to which molecules of water and, to a lesser extent, fat resonate.

The water and oil in the exterior inch or so of food soaks up the microwave energy and turns it into heat; the surrounding air, dishes and walls of the oven do not. The rays do not penetrate far, so trying to cook a whole roast in a microwave is a recipe for disaster. But a thin fish is another story. The cooks in our research kitchen found a fantastic way to make tilapia in the microwave. Sprinkle some sliced scallions and ginger, with a splash of rice wine, over a whole fish, cover it tightly with plastic wrap and microwave it for six minutes at a power of 600 watts. (Finish it off with a drizzle of hot peanut oil, soy sauce and sesame oil.)

The cooking at 600 W is what throws many chefs. To heat at a given wattage, check the power rating on the back of the oven (800 W is typical) and then multiply that figure by the power setting (which is given either as a percentage or in numbers from one to 10 representing 10 percent steps). A 1,000-W oven, for example, produces 600 W at a power setting of 60 percent (or "6"). To "fry" parsley brushed with oil, cook it at 600 W for about four minutes. To dry strips of marinated beef into jerky, cook at 400 W for five minutes, flipping the strips once a minute.

If you are up for slightly more math, you can perform a kitchen experiment that Albert Einstein would have loved: prove that light really does zip along at almost 300 million meters per second. Cover a cardboard disk from a frozen pizza with slices of Velveeta and microwave it at low power until several melted spots appear. (You don't want it rotating, so if your oven has a carousel, prop the cardboard above it.) Measure the distance (in meters) between the centers of the spots. That distance is half the wavelength of the light, so if you double it and multiply by 2.45 billion (the frequency in cycles per second), the result is the velocity of the rays bouncing about in your oven.

—W. Wayt Gibbs and Nathan Myhrvold

Myhrvold is author and Gibbs is editor of Modernist Cuisine: The Art and Science of Cooking *(The Cooking Lab, 2011).*

SUSPECT SCIENCE

"The subjects' brains responded to the sound of their phones as they would respond to the presence … of a … family member."

—From an October op-ed piece in the *New York Times* describing a brain-imaging study purporting to show that iPhone users "loved" their phones. The *Times* later published a letter signed by 45 neuroscientists explaining that "there is rarely a one-to-one mapping between any brain region and a single mental state."

Do you have a recent suspect science statement to submit? E-mail it, along with source material, to submit@sciam.com

RYAN MATTHEW SMITH *Modernist Cuisine LLC*

COMMENT AT ScientificAmerican.com/dec2011

BIOMEDICAL ENGINEERING

A Circuit in Every Cell

Progress for tiny biocomputers

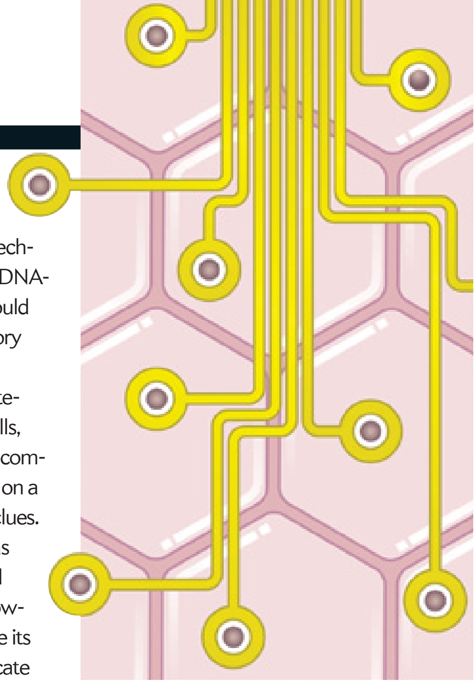

ILLUSTRATION BY THOMAS FUCHS

Researchers in nanomedicine have long dreamed of an age when molecular-scale computing devices could be embedded in our bodies to monitor health and treat diseases before they progress. The advantage of such computers, which would be made of biological materials, would lie in their ability to speak the biochemical language of life.

Several research groups have recently reported progress in this field. A team at the California Institute of Technology, writing in the journal *Science*, made use of DNA nanostructures called seesaw gates to construct logic circuits analogous to those used in microprocessors. Just as silicon-based components use electric current to represent 1's and 0's, bio-based circuits use concentrations of DNA molecules in a test tube. When new DNA strands are added to the test tube as "input," the solution undergoes a cascade of chemical interactions to release different DNA strands as "output." In theory, the input could be a molecular indicator of a disease, and the output could be an appropriate therapeutic molecule. A common problem in constructing a computer in a test tube is that it is hard to control which interactions among molecules occur. The brilliance of the seesaw gate is that a particular gate responds only to particular input DNA strands.

In a subsequent *Nature* paper, the Caltech researchers showed off the power of their technique by building a DNA-based circuit that could play a simple memory game. A circuit with memory could, if integrated into living cells, recognize and treat complex diseases based on a series of biological clues.

This circuitry has not been integrated into living tissue, however, in part because its ability to communicate with cells is limited. Zhen Xie of the Massachusetts Institute of Technology and his collaborators have recently made progress on this front. As they reported in *Science*, they designed an RNA-based circuit that was simpler but could still distinguish modified cancer cells from noncancerous cells and, more important, trigger the cancer cells to self-destruct.

Both techniques have been used only in artificial scenarios. Yet the advances in DNA-based circuits offer a new, powerful platform to potentially realize researchers' long-held biocomputing dreams.

—*Tim Requarth and Greg Wayne*

PARTICIPATE

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PHYSIOLOGY

Vitamins, Minerals and MicroRNA

The food we eat may control our genes

"You are what you eat." The old adage has for decades weighed on the minds of consumers who fret over responsible food choices. Yet what if it was literally true? What if material from our food actually made its way into the innermost control centers of our cells, taking charge of fundamental gene expression?

That is in fact what happens, according to a recent study of plant-animal microRNA transfer led by Chen-Yu Zhang of Nanjing University in China. MicroRNAs are short sequences of nucleotides—the building blocks of genetic material. Although microRNAs do not code for proteins, they prevent specific genes from giving rise to the proteins they encode. Blood samples from 21 volunteers were tested for the presence of microRNAs from crop plants, such as rice, wheat, potatoes and cabbage.

The results, published in the journal *Cell Research,* showed that the subjects' bloodstream contained approximately 30 different microRNAs from commonly eaten plants. It appears that they can also alter cell function: a specific rice microRNA was shown to bind to and inhibit the activity of receptors controlling the removal of LDL—"bad" cholesterol—from the bloodstream. Like vitamins and minerals, microRNA may represent a previously unrecognized type of functional molecule obtained from food.

The revelation that plant microRNAs play a role in controlling human physiology highlights the fact that our bodies are highly integrated ecosystems. Zhang says the findings may also illuminate our understanding of co-evolution, a process in which genetic changes in one species trigger changes in another. For example, our ability to digest the lactose in milk after infancy arose after we domesticated cattle. Could the plants we cultivated have altered us as well? Zhang's study is another reminder that nothing in nature exists in isolation.

—Anne-Marie C. Hodge

PHYSICS

Fluid Dynamics in a Cup

Scientists puzzle out when and why coffee spills

At a recent math conference, Rouslan Krechetnikov watched his colleagues gingerly carry cups of coffee. Why, he wondered, did the coffee sometimes spill and sometimes not? A research project was born.

Although the problem of why coffee spills might seem trivial, it actually brings together a variety of fundamental scientific issues. These include fluid mechanics, the stability of fluid surfaces, interactions between fluids and structures, and the complex biology of walking, explains Krechetnikov, a fluid dynamicist at the University of California, Santa Barbara.

In experiments, he and a graduate student monitored high-speed video of the complex motions of coffee-filled cups people carried, investigating the effects of walking speed and variability among those individuals. Using a frame-by-frame analysis, the researchers found that after people reached their desired walking speed, motions of the cup consisted of large, regular oscillations caused by walking, as well as smaller, irregular and more frequent motions caused by fluctuations from stride to stride, and environmental factors such as uneven floors and distractions.

Coffee spilling depends in large part on the natural oscillation frequency of the beverage—that is, the rate at which it prefers to oscillate, much as every pendulum swings at a precise frequency given its length and the gravitational pull it experiences. When the frequency of the large, regular motions that a cuppa joe experiences is comparable to this natural oscillation frequency, a state of resonance develops: the oscillations reinforce one another, much as pushing on a playground swing at the right point makes it go higher and higher, and the chances of coffee sloshing its way over the edge rise. The small, irregular movements a cup sees can also amplify liquid motion and thus spilling. These findings were to be detailed at a November meeting of the American Physical Society in Baltimore.

Once the key relations between coffee motion and human behavior are understood, it might be possible to develop strategies to control spilling, "such as using a flexible container to act as a sloshing absorber," Krechetnikov says. A series of rings arranged up and down the inner wall of a container might also impede the liquid oscillations. *—Charles Q. Choi*

BUSSE YANKUSHEV *Alamy (rice)*; ANTHONY BRADSHAW *Getty Images (coffee)*


Goldman Sachs
SanDisk Mobile Ultra 64GB micro SD XC
HOW A LONG-TERM PLAN TO HELP AN INNOVATIVE COMPANY GROW
ENDED UP CHANGING MILLIONS OF PEOPLE'S LIVES
PROGRESS IS EVERYONE'S BUSINESS
More than two decades ago, a group of engineers envisioned a day when flash memory would change the world — making technologies like smartphones, tablets and digital cameras possible. Goldman Sachs helped them realize that vision. Over the years, we've provided the advice and access to capital that's helped SanDisk grow from a start-up to a global innovator driving the mobility revolution. Now, their 3,800 employees and breakthrough technologies enable us to talk, text, work, play, take pictures and share moments anyplace, anytime we want. See the story at goldmansachs.com/progress
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JIM WILSON *Redux Pictures*

MILESTONE

Freedom Fighter

Which side was Steve Jobs on?

In 1977, 22-year-old Steve Jobs introduced the world to one of the first self-contained personal computers, the Apple II. The machine was a bold departure from previous products built to perform specific tasks: turn it on, and there was only a blinking cursor awaiting further instruction. Some owners were inspired to program the machines themselves, but others could load up software written and shared or sold by others more skilled or inspired.

Later, when Apple's early lead in the industry gave way to IBM, Jobs and company fought back with the now classic Super Bowl advertisement promising a break from the alleged Orwellian ubiquity of Big Blue. "Unless Apple does it, no one will be able to innovate except IBM," said Jobs's handpicked CEO John Sculley.

In 1984 Jobs delivered the Macintosh. The blinking cursor was gone. Unlike prior PCs, the Mac was useful even without adding software. Turn it on, and the first thing it did, literally, was smile.

Under this friendly exterior, the Mac retained the essence of the Apple II and the IBM PCs: outside developers could write software and share it directly with users.

The rise of the Internet brought a new dimension to this openness. Users could run new code within seconds of encountering it online. This was deeply empowering but also profoundly dangerous. The cacophony of available code began to include viruses and spyware that can ruin a PC—or make the experience of using one so miserable that alternatives seem attractive.

Jobs's third big new product introduction came 30 years after his first. It paid homage to both fashion and fear. The iPhone, unveiled in 2007, did for mobile phones what the Mac did for PCs and the iPod did for MP3 players, setting a new standard for ease of use, elegance and cool. But the iPhone dropped the fundamental feature of openness. Outsiders could not program it. "We define everything that is on the phone," Jobs said. "You don't want your phone to be like a PC. The last thing you want is to have loaded three apps on your phone, and then you go to make a call and it doesn't work anymore."

Being closed to outsiders made the iPhone reliable and predictable. In that first year those who dared hack the phone to add features or to make it compatible with providers other than AT&T risked having it "bricked"—completely and permanently disabled—on the next automatic update from Apple. It was a far cry from the Apple II's ethos, and it raised objections.

Jobs answered his critics with the App Store in 2008. Outside coders were welcomed back, and thousands of apps followed. But new software has to go through Apple, which takes a 30 percent cut, along with 30 percent of new content sales such as magazine subscriptions. Apple reserves the right to kill any app or content it doesn't like. No more surprises.

As goes the iPhone, so perhaps goes the world. The nerds of today are coding for cool but tethered gizmos, like the iPhone, and Web 2.0 platforms, like Facebook and Google Apps—attractive all, but controlled by their makers in a way even the famously proprietary Bill Gates never achieved with Windows. Thanks to iCloud and other services, the choice of a phone or tablet today may lock a consumer into a branded silo, making it hard for him or her to do what Apple long importuned potential customers to do: switch.

Such walled gardens can eliminate what we now take for granted and what Jobs originally represented: a world in which mainstream technology can be influenced, even revolutionized, out of left field and without intermediation. Today control increasingly rests with the legislators and judges who discipline platform makers. Enterprising law-enforcement officers with a warrant can flick a distant switch and turn a standard mobile phone into a roving mic or eavesdrop on occupants of cars equipped with travel assistance systems. These opportunities are arising not only in places under the rule of law but also in authoritarian states.

Curtailing abuse will require borrowing and adapting some of the tools of the hidebound, consumer-centric culture that many who love the Internet seek to supplant. A free Net may depend on some wisely developed and implemented locks and a community ethos that secures the keys to those locks among groups with shared norms and a sense of public purpose rather than in the hands of one gatekeeper.

In time, the brand names may change; Android may tighten up its control of outside code, and Apple could ease up a little. Yet the core battle between the freedom of openness and the safety of the walled garden will remain. It will be fought through information appliances that are not just products but also services, updated through a network by the constant dictates of their makers. Jobs, it seems, left his mark on both sides on the tug-of-war over Internet openness.

—Jonathan Zittrain

COMMENT AT ScientificAmerican.com/dec2011

EDUCATION

This Year, Give Them Brains

Each year we poll scientists and educators on ideas for books, puzzles and toys that foster inquiry. This season's picks range from a top that never stops spinning to a build-it-yourself skull. —*Anna Kuchment*

1 YOUR BODY PUZZLE

$24.95 at fatbraintoys.com; ages 4 and up

A five-layer birch puzzle lets kids peer inside the human body, revealing the digestive tract, nerves and skeleton. Katy Shepard, a Ph.D. candidate in neuroscience at Emory University, says her three-year-old cousin received this puzzle after he pointed to his skin and asked, "What comes next?"

2 LIFE CYCLE STACKING BLOCKS

$19.95 at forsmallhands.com; ages 2 to 6

Paperboard boxes that stack nearly three feet high and feature beautiful illustrations of the life cycles of the butterfly and frog are accompanied by an informative poem, says Julie Frey, a fifth grade teacher at Stuard Elementary School in Aledo, Tex.

3 SKULL PUZZLE

$23 at theevolutionstore.com; ages 8 and up

This 39-piece 3-D puzzle comes with a removable brain. "This puzzle is educational, challenging and, most important, fun," says Kent Kirshenbaum, a chemistry professor at New York University. "Bonus: the jaw swings open and shut hauntingly after you complete it."

4 BONES: SKELETONS AND HOW THEY WORK

by Steve Jenkins (Scholastic, 2010); ages 7 and up

Michelle Nijhuis, a biologist and author, recommended this book and the two following ones. (For more of her suggestions, go to lastwordonnothing.com.) *Bones*, she writes, has fantastic illustrations and "is also great for inspiring hands-on research."

5 FAR FROM SHORE: CHRONICLES OF AN OPEN OCEAN VOYAGE

by Sophie Webb (Houghton Mifflin, 2011); ages 9 to 12

This book chronicles the author's four-month-long Pacific research voyage. "Webb describes her work in some depth, but she emphasizes not the results but the experience: the starlit nights on deck, the sightings of dolphins and whales and seabirds, and daily life with her fellow scientists," Nijhuis writes.

6 TUESDAY

by David Wiesner (Clarion, 1997); ages 5 to 8

"Late one Tuesday evening a mob of frogs flies through town on lily pads, disappearing as quickly as it came. Why? This almost wordless story doesn't say, leaving kids free to form their own theories about spontaneous frog flight," Nijhuis says.

7 EVOLUTION: HOW WE AND ALL LIVING THINGS CAME TO BE

by Daniel Loxton (2010);
$18.95 at kidscanpress.com; ages 8 to 13

Eugenie Scott, executive director of the National Center for Science Education, touts this book as "an excellent introduction to a topic not frequently covered in children's books. There's more to evolution than dinosaurs, after all!"

8 MAGIC BRIKS BRISTLE BLOCKS

$26.95 at kaplanco.com; ages 3 and up

Never underestimate simple building blocks. Noah Cowan, an associate professor at Johns Hopkins University's Whiting School of Engineering, says they are "an essential component in developing a child's ability to reason about space, time and even challenging concepts like entropy. Bristle blocks are particularly good for young children who don't yet have the dexterity for Legos—and, frankly, bristle blocks are even

Photograph by Lucas Zarebinski

more open-ended because the connector density is higher."

9 SHARK IN A JAR—*SQUALUS ACANTHIAS*

$29 at theevolutionstore.com

This real baby shark taken from an adult caught by a commercial fisher "offers a launching point for discussions about the differences between sharks and bony fish, the diverse ways sharks bear their young, and the importance of conservation for threatened shark species," N.Y.U.'s Kirshenbaum says.

10 SCIENCE KITS FROM THAMES & KOSMOS

From $13.95 at thamesandkosmos.com; ages 5 and up

Christof Koch, a professor of cognitive and behavioral biology at the California Institute of Technology, grew up playing with these designer sets, many made by a 189-year-old German company. "These days kids see computer simulations and watch YouTube but don't do that much with their own hands anymore," he says. More than 60 different kits are available for various ages and specialties—from chemistry and biology to energy and forensics.

11 NON-STOP TOP WITH BUILT-IN LIGHT SHOW

$14.99 at amazon.com

This battery-powered top has a motor with an eccentric weight inside that keeps it spinning until the battery runs out. Matt Moses, who just earned his Ph.D. in mechanical engineering at Johns Hopkins, asks these questions when showing it to students:

"1. Would the top work if you spun it on a frictionless surface?

"2. Suppose you were in orbit inside the International Space Station. If you spun it in midair, would it still work?

"3. If the weight inside were not eccentric—that is, if it were perfectly balanced on the motor—would the top still work?

"4. Does the weight spin in the same direction the top is spinning in or in the opposite direction?"

12 GIANT MICROBES

From $8.95 at giantmicrobes.com

These fuzzy replicas of human cells, viruses and bacteria include the common cold (rhinovirus), neurons, and red and white blood cells. "The large size and kid-friendly plush help students visualize microscopic structures," says Emory's Shepard.

Best of the Blogs

PHYSICS

Why Neutrinos Might Wimp Out

Particles that go beyond light speed? Not so fast, many theoretical physicists say

In case you missed the news, a team of physicists reported in September that the tiny subatomic particles known as neutrinos could violate the cosmic speed limit set by Einstein's special theory of relativity. The researchers, working on an experiment called OPERA, beamed neutrinos through the earth's crust, from CERN, the laboratory for particle physics near Geneva, to Gran Sasso National Laboratory in L'Aquila, Italy, an underground physics lab. According to the scientists' estimates, the neutrinos arrived at their destination around 60 nanoseconds quicker than the speed of light.

Experts urged caution, especially because an earlier measurement of neutrino velocity had indicated, to high precision and accuracy, that neutrinos do respect the cosmic speed limit. In a terse paper posted online on September 29, Andrew Cohen and Sheldon Glashow of Boston University calculated that any neutrinos traveling faster than light would lose energy after emitting, and leaving behind, a trail of slower particles that would be absorbed by the earth's crust. This trace would be analogous to a sonic boom left behind by a supersonic fighter jet.

Yet the neutrinos detected at Gran Sasso were just as energetic as when they left Switzerland, Cohen and Glashow point out, casting doubt on the veracity of the speed measurements. "When all particles have the same maximal attainable velocity, it is not possible for one particle to lose energy by emitting another," Cohen explains. "But if the maximal velocities of the particles involved are not all the same," then it can happen.

An effect of this type is well known in cases where electrons have the higher speed limit (light speed), and light itself has the lower one because it is slowed down by traveling in a medium, such as water or air. Electrons, then, can move in the medium at a speed higher than the maximum speed of photons in the same medium and can lose energy by emitting photons. This transfer of energy between particles with different speed limits is called Cherenkov radiation, and it makes the reactor pools of nuclear power stations glow with a bluish light.

In the neutrinos' case, Cohen and Glashow calculate that the wake would mostly consist of electrons paired with their antimatter twins, positrons. Crucially, the rate of production of these electron-positron pairs is such that a typical superluminal neutrino emitted at CERN would lose most of its energy before reaching Gran Sasso. Then again, perhaps they were not superluminal to begin with.

"I think this seals the case," says Lawrence M. Krauss, a theoretical physicist at Arizona State University. "It is a very good paper." So was Albert Einstein right after all? Einstein's relativity superseded Isaac Newton's physics, and physicists will no doubt keep trying to find glitches in Einstein's theories, too. "We never stop testing our ideas," Cohen says. "Even those that have been established well." *—Davide Castelvecchi*

BEHAVIOR

Yawn of the Tortoise

Sleepiness and boredom aren't always contagious

The following post is from a series about the annual Ig Nobel Prizes in science, which honor "achievements that first make people laugh and then make them think." They were awarded in September in Cambridge, Mass.

PAUL A. SOUDERS *Corbis*

Now we come to the Ig Nobel Physiology Prize. Yawns are notoriously contagious in humans and in other social animals, especially primates. In humans, yawning has been thought to do various things, including cooling the brain, increasing arousal when you're sleepy and, possibly, helping to synchronize group behavior.

Could yawning be a form of unconscious empathy? This would mean that in order to have a contagious yawn, the animals involved would have to be capable of empathy, of fellow feeling. We know that dogs and primates, and humans, probably are, but that means we can't really test for whether it's empathy or not. We need a species that is social but probably can't feel for its compatriots.

That's where tortoises come in. To test whether yawning requires empathy and thus get at the real purpose that yawning might serve, Anna Wilkinson of the University of Lincoln in England and her colleagues took a group of red-footed tortoises that lived together and trained one of them to yawn when exposed to a red square. Then they had tortoises watch the trained tortoise in action and checked them for yawns. The researchers also checked for yawns when no other tortoise was present and when the trained tortoise had no red square and so wasn't yawning.

What they got was a big, fat negative. The test tortoises showed no notice of the other animals' huge yawns. This may mean that contagious yawning is *not* just the result of a fixed-action pattern triggered when you see someone else yawn. If that were the case, the tortoises would have yawned right along with their compatriots. Contagious social yawning may require something more, a social sense or a sense of empathy resulting from complex social interactions. Of course, it could also mean that tortoises are just a really bad choice for contagious yawning. But the social explanation seems a little more supported. ***—From the Scicurious Brain at http://blogs.scientificamerican.com/scicurious-brain***

ASTRONOMY

Universal Alignment

Could the cosmos have a point?

Galaxies may move faster in certain directions.

The universe has no center and no edge, no special regions tucked in among the galaxies and light. No matter where you look, it's the same—or so physicists thought. This cosmological principle—one of the foundations of the modern understanding of the universe—has come into question recently as astronomers find evidence, subtle but growing, of a special direction in space.

The first and most well-established data point comes from the cosmic microwave background (CMB), the so-called afterglow of the big bang. As expected, the afterglow is not perfectly smooth—hot and cold spots speckle the sky. In recent years, however, scientists have discovered that these spots are not quite as randomly distributed as they first appeared—they align in a pattern that points out a special direction in space. Cosmologists have theatrically dubbed it the "axis of evil."

More hints of a cosmic arrow come from studies of supernovae, stellar cataclysms that briefly outshine entire galaxies. Cosmologists have been using supernovae to map the accelerating expansion of the universe (a feat that garnered this year's Nobel Prize in Physics). Detailed statistical studies reveal that supernovae are moving even faster in a line pointing just slightly off the axis of evil. Similarly, astronomers have measured galaxy clusters streaming through space at a million miles an hour toward an area in the southern sky.

What could all this mean? Perhaps nothing. "It could be a fluke," says Dragan Huterer, a cosmologist at the University of Michigan at Ann Arbor, or it could be a subtle error that has crept into the data (despite careful efforts). Or, Huterer says, perhaps we are seeing the first signs of "something amazing." The universe's first burst of expansion could have lasted a little longer than we thought, introducing a tilt to it that still persists today. Another possibility is that at large scales, the universe could be rolled up like a tube, curved in one direction and flat in the others, according to Glenn D. Starkman, a cosmologist at Case Western Reserve University. Alternatively, the so-called dark energy—the bewildering stuff accelerating the universe's expansion—might act differently in different places.

For now, the data remain preliminary—subtle signs that something may be wrong with our standard understanding of the universe. Scientists are eagerly anticipating the data from the Planck satellite, which is currently measuring the CMB from a quiet spot 930,000 miles up. It will either confirm earlier measurements of the axis of evil or show them to be ephemera. Until then, the universe could be pointing us anywhere. *—Michael Moyer*

NASA/CXC/IOA/A. FABIAN ET AL. *(x-ray)*; NRAO/VLA/G. TAYLOR *(radio)*; NASA/ESA/HUBBLE HERITAGE/STSCI/AURA AND A. FABIAN *University of Cambridge/IoA (optical)*

COMMENT AT ScientificAmerican.com/dec2011


Colletes bee

PHYSIOLOGY

From Pollen to Polyester

A materials scientist explains how her research into bees could help us make sturdy recyclable containers in the future

Polyester bees are all over the Northeast. The interesting thing about them is that they dig underground tunnels, about the width of your pinky finger, where they lay their eggs. To protect their larvae from heat, cold, fungus, bacteria and other dangers, the bees line these chambers with a clear, cellophanelike substance. The larvae then live underground for most of their lives in these reinforced cells.

I kind of stumbled on polyester, or *Colletes,* bees somewhere on the Internet and eventually got samples of their nest cells from the American Museum of Natural History in New York City. We haven't published our work yet, but we have been looking at these cells and trying to figure out what they're made of.

The bad news is that these cells are really hard to study because their job is to be hard to break down. We found ourselves in this catch-22: anything nasty enough to break them down was too nasty to put into our equipment and anything we could put into our equipment wouldn't break them down.

But what we did show was that it's not just plastic. There are actually silk fibers that the bees lay down first, and the plastic is put down on top of the fibers—like fiberglass—and that makes it really durable. We're working with bacteriologists to see if we can find a bacterium that will break down the plastic.

We care about this material for two reasons. The official reason is that it's a fascinating biologically derived material that isn't biodegradable. So I don't know if you ever do this, but I occasionally forget about spaghetti in the back of my fridge. You wind up with a sealed plastic container that has decomposing stuff inside. You don't want your container to also be part of the decomposing stuff, but we also don't want to keep filling our landfills with containers. This could be a material that's robust under normal circumstances but can be broken down and reused.

PROFILE

NAME
Debbie Chachra

TITLE
Associate professor of materials science, Franklin W. Olin College of Engineering

LOCATION
Needham, Mass.

The second reason I care about this is that it's emblematic of the fact that there's an enormous amount we don't know about the world around us. It makes me wonder how many other things there are like this.

—As told to Rose Eveleth

COURTESY OF GILL PRATT *Olin College*

COMMENT AT ScientificAmerican.com/dec2011

COURTESY OF ACUÑA FOTOGRAFÍA AND GIJÓN AQUARIUM

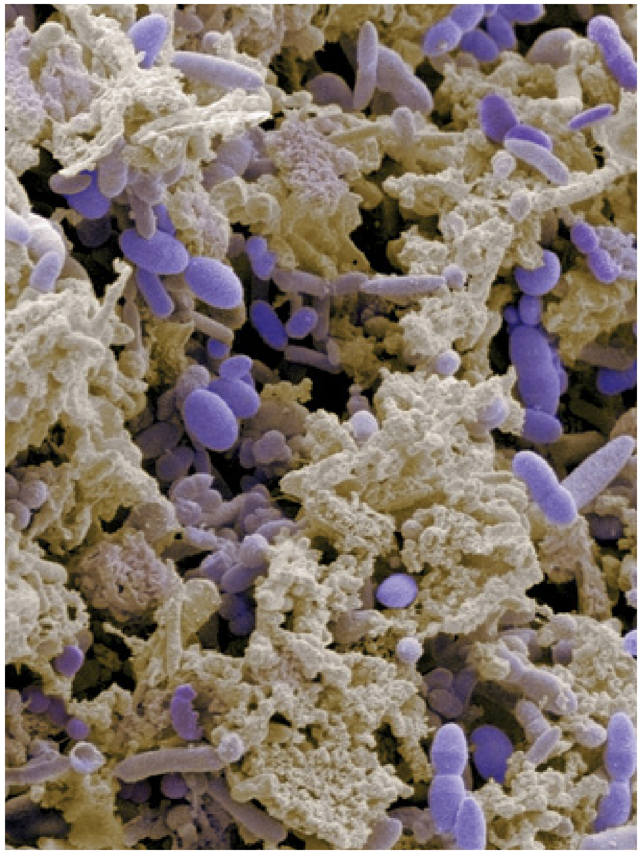
WHAT IS IT?

Attack of the jellyfish: As predators, jellyfish appear to be slow and passive. Unable to swim to and chase their prey, most drift along, creating tiny eddies to guide food toward their tendrils. Yet in waters from the Sea of Japan to the Black Sea, jellyfish, like those pictured here, are thriving as many of their competitors are eliminated by overfishing and other human impacts. How have these drifters reversed millions of years of fish dominance, seemingly overnight? Writing in the journal *Science,* biologist José Luis Acuña of the University of Oviedo in Spain and his colleagues suggest that jellyfish are just as effective at catching prey and turning it into energy as fishes. In fact, they have set the stage for a takeover—dubbed the "gelatinous ocean" by some scientists. "We need research to be sure of what new ecological scenarios are arising," Acuña says. "It is time to take [jellyfish] seriously." *—David Biello*

Maryn McKenna is a journalist , a blogger and author of two books about public health. She writes about infectious diseases, global health and food policy.

Swapping Germs

A potentially beneficial but unusual treatment for serious intestinal ailments may fall victim to regulatory difficulties



Straight poop: **Bacteria shed from the intestine (*some of which are colored purple here*) make up much of human feces.**

Marion Browning of North Providence, R.I., was at her wit's end. The 79-year-old retired nurse had suffered from chronic diarrhea for almost a year. It began after doctors prescribed antibiotics to treat her diverticulitis, a painful infection of small pouches in the wall of the colon. The regimen also killed friendly bacteria that lived in Browning's intestines, allowing a toxin-producing organism known as *Clostridium difficile* to take over and begin eating away at the entire lining of her gut.

For months Browning was in and out of her doctor's office, getting big-gun antibiotics to suppress the *C. difficile* infection. Each time a course of treatment ended she would feel better for a while. But her strain of *C. difficile* was stubborn: a few of the destructive bacteria always survived. Within a few days they would begin multiplying, and the racking diarrhea would recur. After four rounds of antibiotics, her gastroenterologist told her that he had done all he could think of. He recommended that she see Colleen Kelly, a clinical faculty member at Brown University's medical school, who was trying something new.

Kelly proposed a treatment that sounded both logical and strangely unmedical. Normally, she told Browning, the friendly bacteria that reside in the human intestine maintain a seesawing balance that keeps pathogenic bacteria in check. That equilibrium can be temporarily disrupted—as with standard antibiotic treatment—but it nearly always returns to stability. Browning's own bacterial community had lost that ability, probably for good. Still, there was a way to restore normality, Kelly said. She could replace Browning's bacteria completely, by inserting into her colon a diluted sample of stool from someone whose intestinal health was good. If the good bacteria in the donated stool took hold and recolonized her intestine, the *C. difficile* would be crowded out, and she would be cured.

Browning had never heard of such a procedure—variously called fecal transplant, fecal bacteriotherapy or fecal flora reconstitution—but she was ready to try anything. Kelly asked her to recruit a healthy donor. Browning chose her 49-year-old son. In the fall of 2009 Browning performed the bowel-cleansing routine that precedes a colonoscopy, while her son took an overnight laxative. Kelly diluted the donation, then used colonoscopy instruments to squirt the solution high up in Browning's large intestine. The diarrhea resolved in two days and has never recurred.

"I can't understand why more doctors aren't doing this," says Browning, now 80. Yet a complex combination of federal regulations and research rules—along with just plain squeamishness—could keep the procedure from helping potentially thousands of people who might benefit.

A GROWING THREAT

Browning is not alone in being a success story. In medical journals, about a dozen clinicians in the U.S., Europe and Australia have described performing fecal transplants on about 300 *C. difficile* patients so far. More than 90 percent of those patients recovered completely, an unheard-of proportion. "There is no drug, for anything, that gets to 95 percent," Kelly says. Plus, "it is cheap and it is safe," says Lawrence Brandt, a professor of medicine and surgery at the Albert Einstein College of Medicine, who has been performing the procedure since 1999.

So far, though, fecal transplants remain a niche therapy, practiced only by gastroenterologists who work for broad-minded institutions and who have overcome the ick factor. To become widely accepted, recommended by professional societies and reimbursed by insurers, the transplants will need to be rigorously studied in a randomized clinical trial, in which people taking a treatment are assessed alongside people who are not. Kelly and

TONY BRAIN *Photo Researchers, Inc.*

PROMOTION

The Agenda Setters

Bringing Science to Life

Photos by DARREN SANTOS

CITIES

Rayburn House Office Building, Capitol Hill | Washington DC | September 15, 2011

To celebrate our September issue on CITIES, Scientific American hosted a reception for Washington, D.C. insiders, SA editors and urban experts. Edward Glaeser (of the Kennedy School of Government at Harvard University and a noted author) inspired guests with remarks about spurring innovation, fostering health and creating sustainable growth in cities. Attendees included Maryland Governor Parris N. Glendening and D.C. Councilman Tommy Wells.

Photos by CHRISTINE KAELIN

Family Science Night

Frederick Douglass Center | New York City | October 13, 2011

SCIENTIFIC AMERICAN partnered with the New York Academy of Sciences and the Children's Aid Society to present an evening of science fun based on the growing database of "Bring Science Home" activities available on our site. Visit **scientificamerican.com/BringScienceHome** to try these projects yourself!

several others have drafted a trial design to submit to the National Institutes of Health for grant funding. Yet an unexpected obstacle stands in their way: before the NIH approves any trial, the substance being studied must be granted "investigational" status by the Food and Drug Administration. The main categories under which the FDA considers things to be investigated are drugs, devices, and biological products such as vaccines and tissues. Feces simply do not fit into any of those categories.

The physicians performing the transplants decry the regulatory bottleneck because new treatments for *C. difficile* infection are critically needed. *C. diff,* to use the common medical shorthand, has risen in the past 30 years from a recognized but tolerated consequence of antibiotic treatment to a serious health threat. Since 2000, when a virulent new strain emerged, cases have become much more common, occurring not only in the elderly but in children, pregnant women and people with no obvious health risks. One study estimated that the number of hospitalized adults with *C. diff* more than doubled from about 134,000 patients in 2000 to 291,000 patients in 2005. A second study showed that the overall death rate from *C. diff* had jumped fourfold, from 5.7 deaths per million in the general population in 1999 to 23.7 deaths per million in 2004.

C. diff has also become harder to cure. Thanks to increasing antibiotic resistance, standard treatment now relies on two drugs: metronidazole (Flagyl) and vancomycin. Both medications are so-called broad-spectrum antibiotics, meaning that they work against a wide variety of bacteria. Thus, when they are given to kill *C. diff* infection, they kill most of the gut's friendly bacteria as well. The living space that those bacteria once occupied then becomes available for any *C. diff* organisms that survive the drugs' attack. As a result, roughly 20 percent of patients who have had one episode of *C. diff* infection will have a recurrence; 40 percent of those with one recurrence will have another; and 60 percent of those who experience a second bout are likely to suffer several more. Some victims with no other options must have their colon removed. (A new drug, fidaxomicin, which was approved for *C. diff* infection by the FDA in late May, may lead to fewer relapses because it is a narrow-spectrum antibiotic.)

A SIMPLE PROCEDURE

The details of how the transplantation of microbes eliminates *C. diff* infection have not been well studied, but Alex Khoruts, a gastroenterologist and immunologist at the University of Minnesota who has performed two dozen fecal transplants over the past two years, has demonstrated that the transplanted bacteria do take over the gut, replacing the absent friendly bacteria and outcompeting *C. diff*. In 2010 he analyzed the genetic makeup of the gut flora of a 61-year-old woman so disabled by recurrent *C. diff* that she was wearing diapers and was confined to a wheelchair. His results showed that before the procedure, in which the woman received a fecal sample from her husband, she harbored none of the bacteria whose presence would signal a healthy intestinal environment. After the transplant—and her complete recovery—the bacterial contents of her gut were not only normal but were identical to that of her husband.

Most clinicians who perform fecal transplants ask their patients to find their own donors and prefer that they be a child, sibling, parent or spouse. "For me, it's aesthetic," says Christina Surawicz, a professor of medicine at the University of Washington, who has done transplants on two dozen patients and published an account of the first 19. "There's something very intimate about putting someone else's stool in your colon, and you are already intimate with a spouse."

To ensure safety, the physicians performing the procedure require that donors have no digestive diseases and put them through the same level of screening that blood donation would require. That process imposes a cost in time and logistics because standard rules for medical confidentiality require a donor to be interviewed separately from the potential recipient. It also carries inherent financial penalties. The donor's lab work most likely will not be covered by insurance; the transplant procedure may or may not be covered by the patient's insurance.

Proponents have come up with work-arounds for those possible barriers. Khoruts no longer uses related donors—which requires finding a different individual for every case—but instead has recruited a cadre of "universal donors" from among local health care workers. (He has seen no change in how often the transplants "take.") Last year Michael Silverman of the University of Toronto boldly proposed a yet more streamlined solution: having patients perform the transplants at home with a drugstore enema kit. A drawback, he cautioned in *Clinical Gastroenterology and Hepatology,* is that too much of the stool solution might leak out for the transplant to take. Nevertheless, seven patients with recurrent *C. diff* have safely performed the home version, he wrote, with a 100 percent recovery rate.

NEXT STEPS

Even without large-scale rigorous investigations of fecal transplants, the medical community appears to be coming around to the practice. The *Journal of Clinical Gastroenterology* editorialized in September 2010 that "it is clear from all of these reports that fecal bacteriotherapy using donor stool has arrived as a successful therapy." Albert Einstein's Brandt recently suggested in the same journal that fecal transplants should be the first treatment tried for serious *C. diff* infection rather than a last resort. Increasing research interest in the influence of gut flora on the rest of the body—and on conditions as varied as obesity, anxiety and depression—will likely bring pressure for transplants to be adopted more widely.

Currently three clinical trials of fecal transplants have begun in Canada. In the U.S., however, the research logjam persists. An FDA spokesperson said in an interview that there is no way to determine how the agency might rule on an investigational application until the application is brought. That tosses the initiative back to Kelly and her collaborators, who include Khoruts and Brandt. They hope to file with the FDA before much longer, but Kelly admits to being apprehensive over the possible outcome.

"We hope they will not ask things that we cannot answer," she says. Medical centers need to be able to study the procedure, Kelly argues, "because people are trying it on their own." SA

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Comment on this article at ScientificAmerican.com/dec2011

David Pogue is the personal-technology columnist for the *New York Times* and an Emmy Award–winning correspondent for *CBS News*.

How to See the Invisible

Augumented-reality apps uncover the hidden reality all around you

Everybody's amazed by touch-screen phones. They're so thin, so powerful, so beautiful!

But this revolution is just getting under way. Can you imagine what these phones will be like in 20 years? Today's iPhones and Android phones will seem like the Commodore 64. "Why, when I was your age," we'll tell our grandchildren, "phones were a third of an inch thick!"

Then there are the apps. Right now we're all delighted to do simple things on our phones, like watch videos and play games. But the ingredients in the modern app phone—camera, GPS, compass, accelerometer, gyroscope, Internet connection—make it the perfect device for the next wave of software. Get ready for augmented reality (AR).

That term usually refers to a live-camera view with superimposed informational graphics. The phone becomes a magic looking glass, identifying physical objects in the world around you.

If you're color-blind like me, then apps like Say Color or Color ID represent a classic example of what augmented reality can do. You hold up the phone to a piece of clothing or a paint swatch—and it tells you by name what color the object is, like dark green or vivid red. You've gone to your last party wearing mismatched clothes.

Other apps change what you see. When a reader sent me a link to a YouTube video promoting Word Lens, I wrote back, "Ha-ha, very funny." It looked so magical, I thought it was fake.

But it's not. You point the iPhone's camera at a sign or headline in Spanish. The app magically replaces the original text with an English translation, right there in the video image, in

> The phone becomes **A MAGIC LOOKING GLASS, IDENTIFYING** physical objects in the world around you.

real time—same angle, color, background material, lighting. Somehow the app erases the original text and replaces it with new lettering. (There's an English-to-Spanish mode, too.)

Some of the most promising AR apps are meant to help you when you're out and about. Apps like New York Nearest Subway and Metro AR let you look down at the ground and see colorful arrows that show you which subway lines are underneath your feet. Raise the phone perpendicular to the ground, and you'll see signs for the subway stations—how far away they are and which subway lines they serve.

When you're in a big city, apps like Layar and Wikitude let you peer through the phone at the world around you. They overlay icons for information of your choice: real estate listings, ATM locations, places with Wikipedia entries, public works of art, and so on. Layar boasts thousands of such overlays.

There are AR apps that show you where the hazards are on golf courses (Golfscape GPS Rangefinder), where you parked your car (Augmented Car Finder), who's using Twitter in the buildings around you (Tweet360), what houses are for sale near you and for how much (ZipRealty Real Estate), how good and how expensive a restaurant is before you even go inside (Yelp), the names of the stars and constellations over your head (Star Walk, Star Chart), the names and details of the mountains in front of you (Panoramascope, Peaks), what crimes have recently been committed in the neighborhoods around you (SpotCrime), and dozens more.

Several of these apps are not, ahem, paragons of software stability. And many, like Layar, are pointless outside of big cities because there aren't enough data points to overlay.

As much fun as they are to use, AR apps mean walking through your environment with your eyes on your phone, held at arm's length—a posture with unfortunate implications for social interaction, serendipitous discovery and avoiding bus traffic.

Furthermore, there's already been much bemoaning of our society's decreasing reliance on memory; in the age of Google, nobody needs to learn the presidents, the state capitals or the periodic table. AR apps are only going to make things worse. Next thing you know, AR apps will identify our friends using facial recognition. Can't you just see it? You'll be at a party, and someone will come up to you and say, "Hey, how are you—" (consulting the phone) "—David?"

But every new technology has its rough edges, and somehow we muddle through. Someday we will boggle our grandchildren's minds with tales of life before AR—if we can remember their names. SA

SCIENTIFIC AMERICAN ONLINE
Augmented-reality apps that don't exist but should: ScientificAmerican.com/dec2011/pogue

World Changing Ideas

10 new technologies that will make a difference

Revolutions often spring from the simplest of ideas. When a young inventor named Steve Jobs wanted to provide computing power to "people who have no computer experience and don't particularly care to gain any," he ushered us from the cumbersome technology of mainframes and command-line prompts to the breezy advances of the Macintosh and iPhone. His idea helped to forever change our relationship with technology.

What other simple but revolutionary ideas are out there in the labs, waiting for the right moment to make it big? We have found 10, and in the following pages we explain what they are and how they might shake things up: Computers that work like minds. Batteries you can top off at the pump. A crystal ball made from data (the focus of a feature on page 52). Consider this collection our salute to the power of a simple idea. —*The Editors*

Photographs by Dan Saelinger

MEDICINE

The Forever Health Monitor

Your smartphone can monitor your vital signs in real time, alerting you to the first sign of trouble

MOST PEOPLE HEAD TO THEIR DOCTORS IF THEY HAVE CHEST PAIN or a suspicious lump, but signs like these often appear too late. Catching symptoms earlier requires ongoing monitoring—the kind of thing a cell phone might do. Health-scanning systems that exploit the continuous flow of data from cell phones could help eliminate the perilous lag time between the onset of symptoms and diagnosis. Mobile devices could also help care providers identify and treat problems before they become too serious—and too expensive—to address effectively. In theory, such always-on warning systems could slash the 75 percent of health care spending used for chronic disease management and extend life spans by staving off millions of potential health crises.

Beats to go: AliveCor's iPhone ECG system monitors heart rhythms.

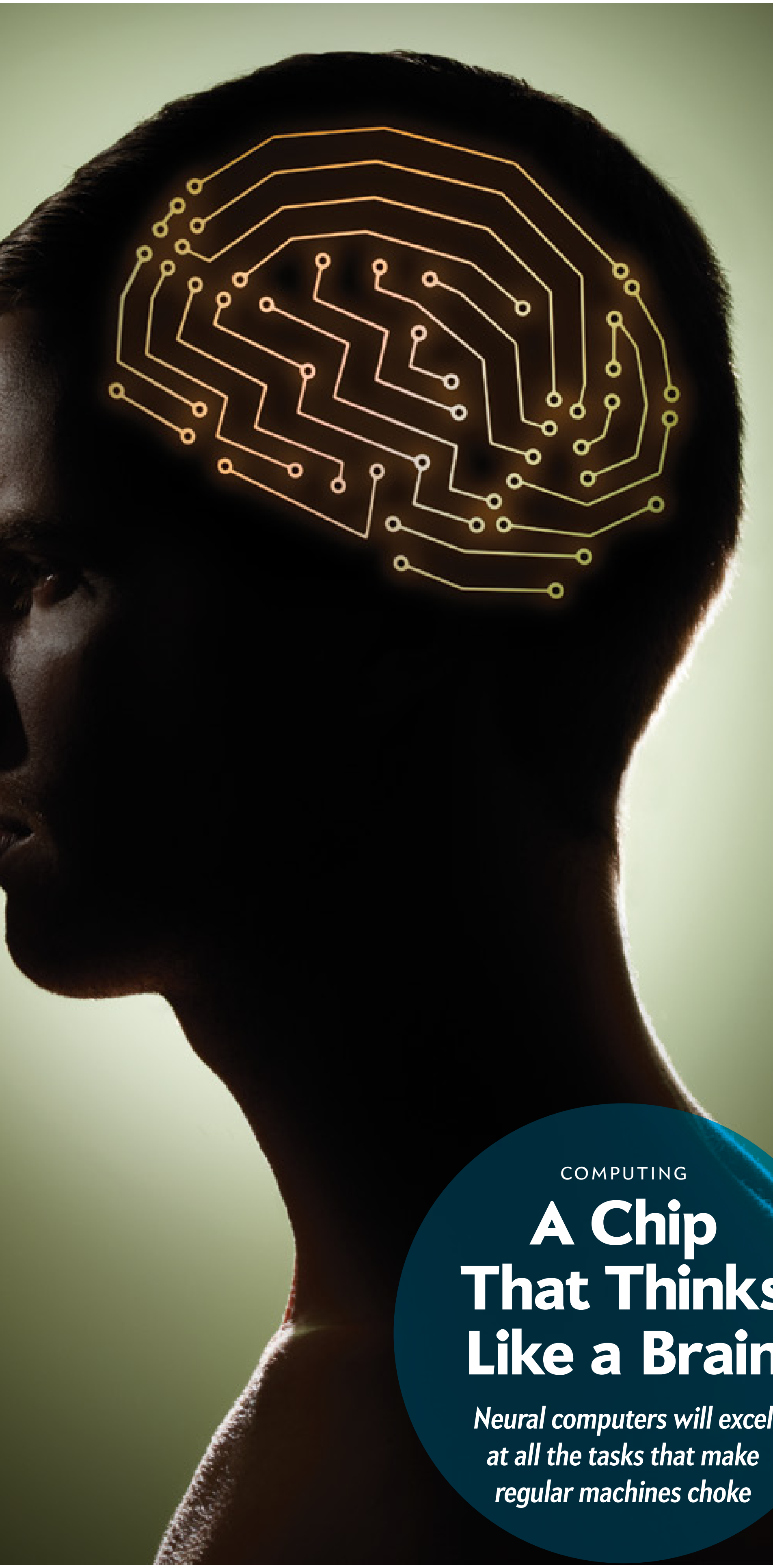
The mobile marketplace is glutted with health apps that are little more than gimmicks, but a few standout systems promise to help users manage chronic conditions or identify red-flag symptoms. AliveCor's iPhone ECG, a plastic phone case that is slated for U.S. Food and Drug Administration approval in early 2012, has two metal electrodes on the back of the case that record heart rhythms whenever users hold the device in both hands or press it against their chest. This real-time electrocardiography (ECG) data can be beamed wirelessly to patients, family members and doctors, alerting them to any heart rhythm irregularities. "It doesn't just give people an early warning but also gives it without the cost associated with conventional ECG tools," says the device's developer, biomedical engineer David Albert. Similarly, French company Withings has developed a blood pressure–monitoring device that works with the iPhone. After users don the sleek white cuff, a reading pops up on the phone's screen within 30 seconds; if the reading is abnormal, a warning also appears. And WellDoc's FDA-approved diabetes application, DiabetesManager, allows patients to enter a variety of real-time data into their phones, such as blood glucose levels, carbohydrates consumed and diabetes medicines taken. The software analyzes all these factors and supplies patients with a recommended action to keep sugar levels in a healthy range (take insulin, eat something). A trial published in September showed that DiabetesManager users have significantly better long-term glucose control than nonusers.

So far the new systems are largely disjointed from one another, and many remain in development. Yet wireless health experts say they represent the beginning of an era when mobile health-monitoring systems will work seamlessly and in concert, giving consumers and their doctors a comprehensive, data-fueled picture of their overall health. "It's technically possible to press a button [on your phone] and say, 'I want to look at my vital signs in real time,'" says Eric Topol, director of the Scripps Translational Science Institute.

The big roadblock is sensor technology. Traditional blood glucose monitors must pierce the skin to work, and few people want to wear a blood pressure cuff or a taped-on electrode everywhere they go. But more convenient alternatives are imminent. Scientists in Japan recently created injectable fluorescent fibers that monitor blood glucose. Topol says a future array of nanoparticle-based sensors that interface with smartphones could achieve more reliable monitoring for vital signs and, most enticingly, earlier detection of disease markers such as antibodies. Sensors that can detect so-called tumor markers, for instance, could send immediate alerts to mobile devices, giving patients the option to start preventive chemotherapy before cancerous cells can get entrenched. Moreover, the simpler mobile health monitoring becomes, the more likely consumers will be to sign up. A 2010 survey found that 40 percent of Americans would pay a monthly subscription fee for a mobile device that would send blood pressure, blood glucose or heart rate data to their doctors.

Paul Sonnier, a vice president at the Wireless-Life Sciences Alliance, points out that resolving health issues early on will be even easier when mobile health monitoring is integrated with genetic analysis. If a patient has a gene that predisposes her to diabetes or cancer early in life, for example, she could potentially wear an unobtrusive sensor that sends word of any unusual developments to her phone. "You'd have an embedded nanosensor to be ahead of the first attack on the islet cells of the pancreas, the first cancerous cell that shows up," Topol says. Should mobile health-monitoring systems reach their potential, they will serve as ever present sentinels that protect people before they know they're in danger. *—Elizabeth Svoboda*

PROP STYLING BY LAURIE RAAB, FOR HALLEY RESOURCES; BRAIN CHIP MODEL: MAKOTO AOKI *Swell NYC*; GROOMING AND SPECIAL EFFECTS: JANE CHOI *Stockland Martel*; COURTESY OF ALIVECOR (*iPhone*)



COMPUTING

A Chip That Thinks Like a Brain

Neural computers will excel at all the tasks that make regular machines choke

DHARMENDRA S. MODHA is probably the only microchip architect on the planet whose team includes a psychiatrist—and it's not for keeping his engineers sane. Rather his collaborators, a consortium of five universities and as many IBM labs, are working on a microchip modeled after neurons.

They call their research "cognitive computing," and its first products, two microchips each made of 256 artificial neurons, were unveiled in August. Right now all they can do is beat visitors at Pong or navigate a simple maze. The ultimate goal, though, is ambitious: to put the neural computing power of the human brain in a small package of silicon. The program, SyNAPSE, which is funded by the U.S. Defense Advanced Research Projects Agency, is building a microprocessor with 10 billion neurons and 100 trillion synapses, roughly equivalent in scale to one hemisphere of the human brain. They expect it to be no bigger than two liters in volume and to consume as much electricity as 10 100-watt lightbulbs.

Despite appearances, Modha insists he is not trying to create a brain. Instead his team is trying to create an alternative to the architecture common to nearly every computer constructed since its invention. Ordinary chips must pass instructions and data through a single, narrow channel, which limits their top speed. In Modha's alternative, each artificial neuron will have its own channel, baking in massively parallel processing capabilities from the beginning. "What we are building is a universal substrate, a platform technology, which can serve as the basis for a wide array of applications," Modha says.

If successful, this approach would be the culmination of 30 years of work on simulated neural networks, says Don Edwards, a neuroscientist at Georgia State University. Even IBM's competitors are impressed. "Neuromorphic processing offers the potential for solving problems that are difficult—some would say impossible—to address through conventional system designs," says Barry Bolding, vice president of Cray, headquartered in Seattle.

Modha emphasizes that cognitive-computing architectures will not replace conventional computers but complement them, preprocessing information from the noisy real world and transforming it into symbols that conventional computers are comfortable with. For example, Modha's chips would excel at pattern recognition, like picking a face out of a crowd, then sending the person's identity to a conventional computer.

If it all sounds a little too much like the rise of the machines, perhaps it is small comfort that these chips would be bad at mathematics. "Just like a brain is inefficient to represent on today's computers, the very fast addition and subtraction that conventional computers are good at is very inefficient on a brainlike network. Neither can replace the other," Modha says. *—Christopher Mims*

MONEY

The Wallet in Your Skin

Forget cell-phone payment systems—just wave your hand to charge it

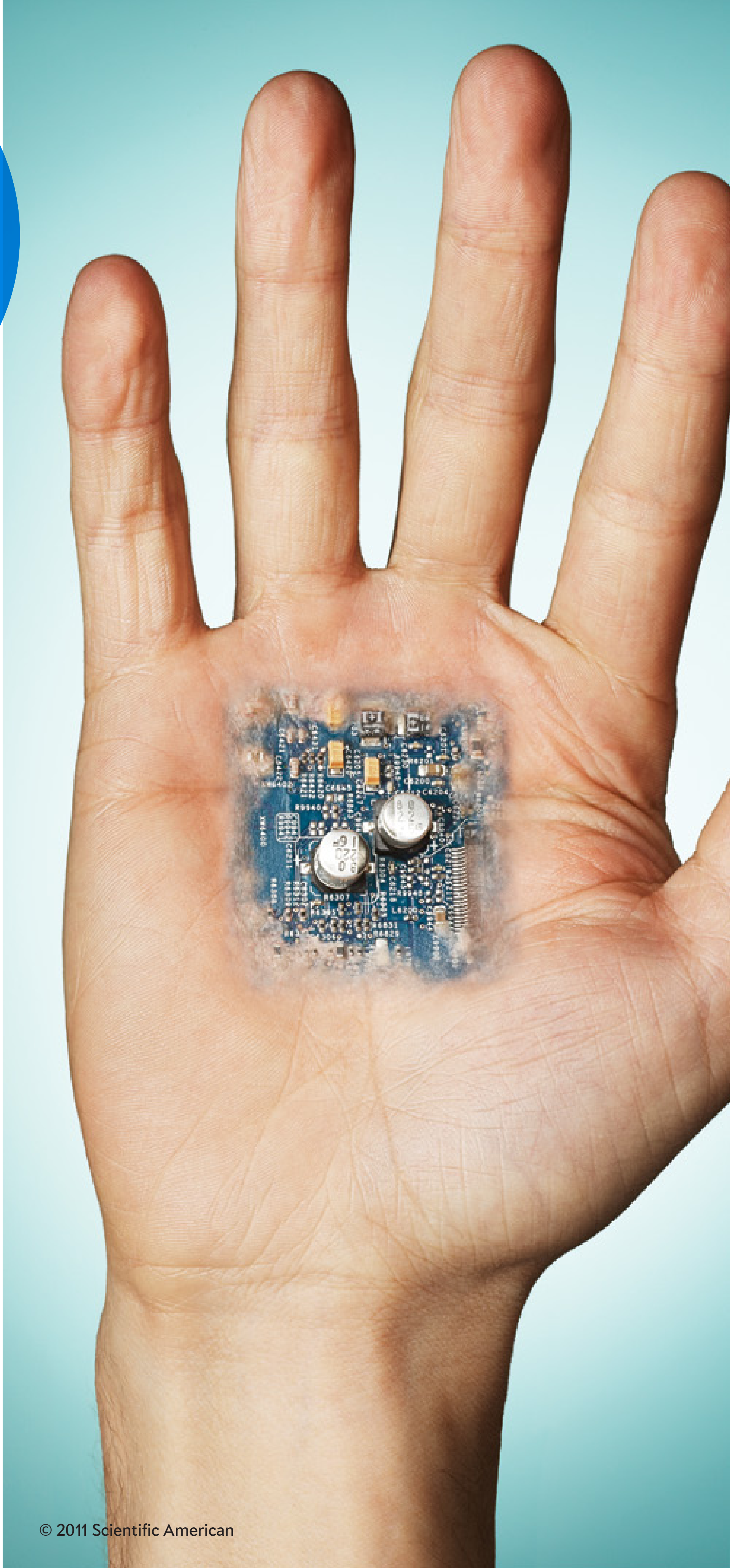
WHEN STUDENTS in Pinellas County schools fill up their lunch trays in the cafeteria and walk over to the cash registers, they just wave their hands and move on to have lunch with their friends. Schools in this Florida county have installed square-inch sensors at the registers that identify each student by the pattern of veins in his or her palm. Buying lunch involves no cards or cash. Their hands are the only wallets they need.

The Fujitsu PalmSecure system they are using allows these young people to get through the line quickly—wait times have been cut in half since the program started—an important consideration in a school where lunch is only 30 minutes long. The same technology is used by Carolinas Healthcare System, an organization that operates more than 30 hospitals, to identify 1.8 million patients, whether or not they are conscious. It is also used as additional authentication for transactions at Japan's Bank of Tokyo-Mitsubishi UFJ.

Many physical characteristics can allow a machine to identify an individual, but only a few of them are both unique and accessible enough to be this straightforward to use. Fingerprints and faces are not as unique as we have been led to believe and can result in false positives. They are also easy to fake. Although irises are unique, capturing them requires someone to peer into a reading device and stare unblinking for several seconds, which is easy to flub and feels intrusive. The three-dimensional configuration of veins in the hand varies highly from person to person and is easy to read with harmless near-infrared light. So why are we still paying for everything with credit cards?

The only barrier to such a "digital wallet" is that banks and technology firms are slow to adopt it, says security guru Bruce Schneier. "All a credit card is, is a pointer to a database," Schneier says. "It's in a convenient rectangular form, but it doesn't have to be. The barriers to entry are not security-based, because security is a minor consideration."

Once a large retailer or government agency implements such a system—imagine gaining access to the subway with just a high five—it has the potential to become ubiquitous. The financial industry already handles substantial amounts of fraud and false positives, and switching to biometrics is not likely to change that burden. It will make purchasing as simple as waving your hand. *—Christopher Mims*



COMPUTING

Computers That Don't Freeze Up

People have to manage their own time. Why can't our machines do the same? New software will keep them humming

JIM HOLT'S SMARTPHONE IS NOT ALL THAT SMART. IT HAS A MAPPING APPLICATION HE USES TO FIND RESTAURANTS, but when he's finished searching, the app continues to draw so much power and memory that he can't even do a simple thing like send a text message, complains Holt, an engineer at Freescale Semiconductor.

Holt's phone highlights a general problem with computing systems today: one part of the system does not know what the other is doing. Each program gobbles what resources it can, and the operating system is too stupid to realize that the one app the user cares about at the moment is getting squeezed out. This issue plagues not only smartphones but personal computers and supercomputers, and it will keep getting worse as more machines rely on multicore processors. Unless the various components of a computer learn to communicate their availabilities and needs to one another, the future of computing may not be able to live up to its glorious past.

Holt and his collaborators in Project Angstrom, a Massachusetts Institute of Technology–led research consortium, have come up with an answer: the "self-aware" computer. In conventional computers, the hardware, software and operating system (the go-between for hardware and software) cannot easily tell what the other components are doing, even though they are all running inside the same machine. An operating system, for example, does not know if a video-player application is struggling, even though someone watching the video would certainly notice the jerky picture.

Last year an M.I.T. team released Application Heartbeats, research software that monitors how all the different applications are faring. It can tell, for instance, that video software is running at a pokey 15 frames per second, not an optimal 30.

The idea is to eventually make operating systems that can detect when applications are running unacceptably slowly and consider potential solutions. If the computer had a full battery, perhaps the operating system would direct more computing power to the app. If not, maybe the operating system would tell the application to use a lower-quality but more efficient set of instructions. The operating system would learn from experience, so it might fix the problem faster the second time around. And a self-aware computer would be able to juggle complex goals such as "run these three programs but give priority to the first one" and "save energy as much as possible, as long as it doesn't interfere with this movie I'm trying to watch."

The next step is to design a follow-on operating system that can tailor the resources going to any one program. If video were running slowly, the operating system would allocate more power to it. If it was running at 40 frames a second, however, the computer might shunt power elsewhere because movies do not look better to the human eye at 40 frames per second than they do at 30. "We're able to save 40 percent of power over standard practice today," says Henry Hoffmann, a doctoral student in computer science at M.I.T. who is working on the software.

Self-aware systems will not only make computers smarter, they could prove essential for managing ever more complex computers in the future, says Anant Agarwal, the project's lead scientist. Over the past decade computer engineers have added more and more basic computing units, called cores, to computers. Today's computers have two to four cores, but future machines will use anywhere from dozens to thousands of cores. That would make the task of splitting up computational tasks among the cores, which programmers now do explicitly, nearly impossible. A self-aware system will take that burden off the programmer, adjusting the program's core use automatically.

Being able to handle so many cores may bring about a whole new level of computing speed, paving the way for a continuation of the trends toward ever faster machines. "As we have very large numbers of cores, we have to have some level of self-aware systems," says John Villasenor, a professor of electrical engineering at the University of California, Los Angeles, who is not involved in Project Angstrom. "I think you'll see some elements of this in the next couple of years." *—Francie Diep*

MONEY

Currency without Borders

The world's first digital currency cuts out the middleman and keeps users anonymous

IMAGINE IF YOU WERE TO WALK INTO A DELI, ORDER A CLUB SANDWICH, throw some dollar bills down and have the cashier say to you, "That's great. All I need now is your name, billing address, telephone number, mother's maiden name, and bank account number." Most customers would balk at these demands, and yet this is precisely how everyone pays for goods and services over the Internet.

There is no currency on the Web that is as straightforward and anonymous as the dollar bill. Instead we rely on financial surrogates such as credit-card companies to handle our transactions (which pocket a percentage of the sale, as well as your personal information). That could change with the rise of Bitcoin, an all-digital currency that is as liquid and anonymous as cash. It's "as if you were taking a dollar bill, squishing it into your computer and sending it out over the Internet," says Gavin Andresen, one of the leaders of the Bitcoin network.

Bitcoins are bits—strings of code that can be transferred from one user to another over a peer-to-peer network. Whereas most strings of bits can be copied ad infinitum (a property that would render any currency worthless), users can spend a Bitcoin only once. Strong cryptography protects Bitcoins against would-be thieves, and the peer-to-peer network eliminates the need for a central gatekeeper such as Visa or PayPal. The system puts power in the hands of the users, not financial middlemen.

Bitcoin borrows concepts from well-known cryptography programs. The software assigns every Bitcoin user two unique codes: a private key that is hidden on the user's computer and a public address that everyone can see. The key and the address are mathematically linked, but figuring out someone's key from his or her address is practically impossible. If I own 50 Bitcoins and want to transfer them to a friend, the software combines my key with my friend's address. Other people on the network use the relation between my public address and private key to verify that I own the Bitcoins that I want to spend, then transfer those Bitcoins using a code-breaking algorithm. The first computer to complete the calculations is awarded a few Bitcoins now and then, which recruits a diverse collective of users to maintain the system.

The first reported Bitcoin purchase was pizza sold for 10,000 Bitcoins in early 2010. Since then, exchange rates between Bitcoin and the U.S. dollar have bounced all over the scale like notes in a jazz solo. Because of the currency's volatility, only the rare online merchant will accept payment in Bitcoins. At this point, the Bitcoin community is small but especially enthusiastic—just like the early adopters of the Internet. *—Morgen Peck*

MATERIALS

Microbe Miners

Bacteria extract metals and clean up the mess afterward

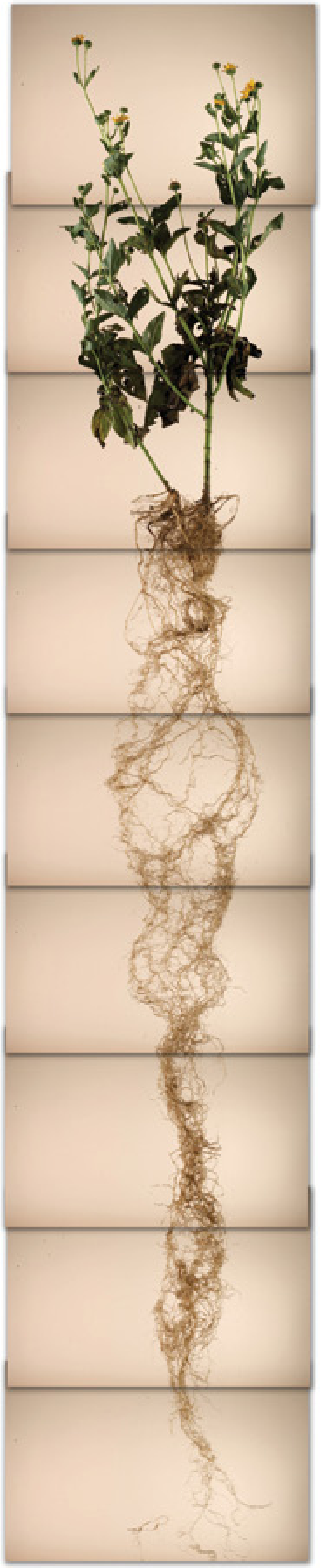
MINING HASN'T CHANGED MUCH SINCE THE Bronze Age: to extract valuable metal from an ore, apply heat and a chemical agent such as charcoal. But this technique requires a lot of energy, which means that it is too expensive for ores with lower metal concentrations.

Miners are increasingly turning to bacteria that can extract metals from such low-grade ores, cheaply and at ambient temperatures. Using the bacteria, a mining firm can extract up to 85 percent of a metal from ores with a metal concentration of less than 1 percent by simply seeding a waste heap with microbes and irrigating it with diluted acid. Inside the heap *Acidithiobacillus* or *Leptospirillum* bacteria oxidize iron and sulfur for energy. As they eat, they generate reactive ferric iron and sulfuric acid, which degrade rocky materials and free the valued metal.

Biological techniques are also being used to clean up acidic runoff from old mines, extracting a few last precious bits of metal in the process. Bacteria such as *Desulfovibrio* and *Desulfotomaculum* neutralize acids and create sulfides that bond to copper, nickel and other metals, pulling them out of solution.

Biomining has seen unprecedented growth in recent years as a result of the increasing scarcity of high-grade ores. Nearly 20 percent of the world's copper comes from biomining, and production has doubled since the mid-1990s, estimates mining consultant Corale Brierley. "What mining companies used to throw away is what we call ore today," Brierley says.

The next step is unleashing bacterial janitors on mine waste. David Barrie Johnson, who researches biological solutions to acid mine drainage at Bangor University in Wales, estimates that it will take 20 years before bacterial mine cleanup will pay for itself. "As the world moves on to a less carbon-dependent society, we have to look for ways of doing things that are less energy-demanding and more natural," Johnson says. "That's the long-term objective, and things are starting to move nicely in that direction." *—Sarah Fecht*



Winter sun: This sunflower is a hybrid of an annual crop flower and a wild perennial relative.

AGRICULTURE

Crops That Don't Need Replanting

Year-round crops can stabilize the soil and increase yields. They may even fight climate change

BEFORE AGRICULTURE, MOST OF THE PLANET WAS COVERED WITH PLANTS THAT LIVED YEAR after year. These perennials were gradually replaced by food crops that have to be replanted every year. Now scientists are contemplating reversing this shift by creating perennial versions of familiar crops such as corn and wheat. If they are successful, yields on farmland in some of the world's most desperately poor places could soar. The plants might also soak up some of the excess carbon in the earth's atmosphere.

Agricultural scientists have dreamed of replacing annuals with equivalent perennials for decades, but the genetic technology needed to make it happen has appeared only in the past 10 or 15 years, says agroecologist Jerry Glover. Perennials have numerous advantages over crops that must be replanted every year: their deep roots prevent erosion, which helps soil hold onto critical minerals such as phosphorus, and they require less fertilizer and water than annuals do. Whereas conventionally grown monocrops are a source of atmospheric carbon, land planted with perennials does not require tilling, turning it into a carbon sink.

Farmers in Malawi are already getting radically higher yields by planting rows of perennial pigeon peas between rows of their usual staple, corn. The peas are a much needed source of protein for subsistence farmers, but the legumes also increase soil water retention and double soil carbon and nitrogen content without reducing the yield of the primary crop on a given plot of land.

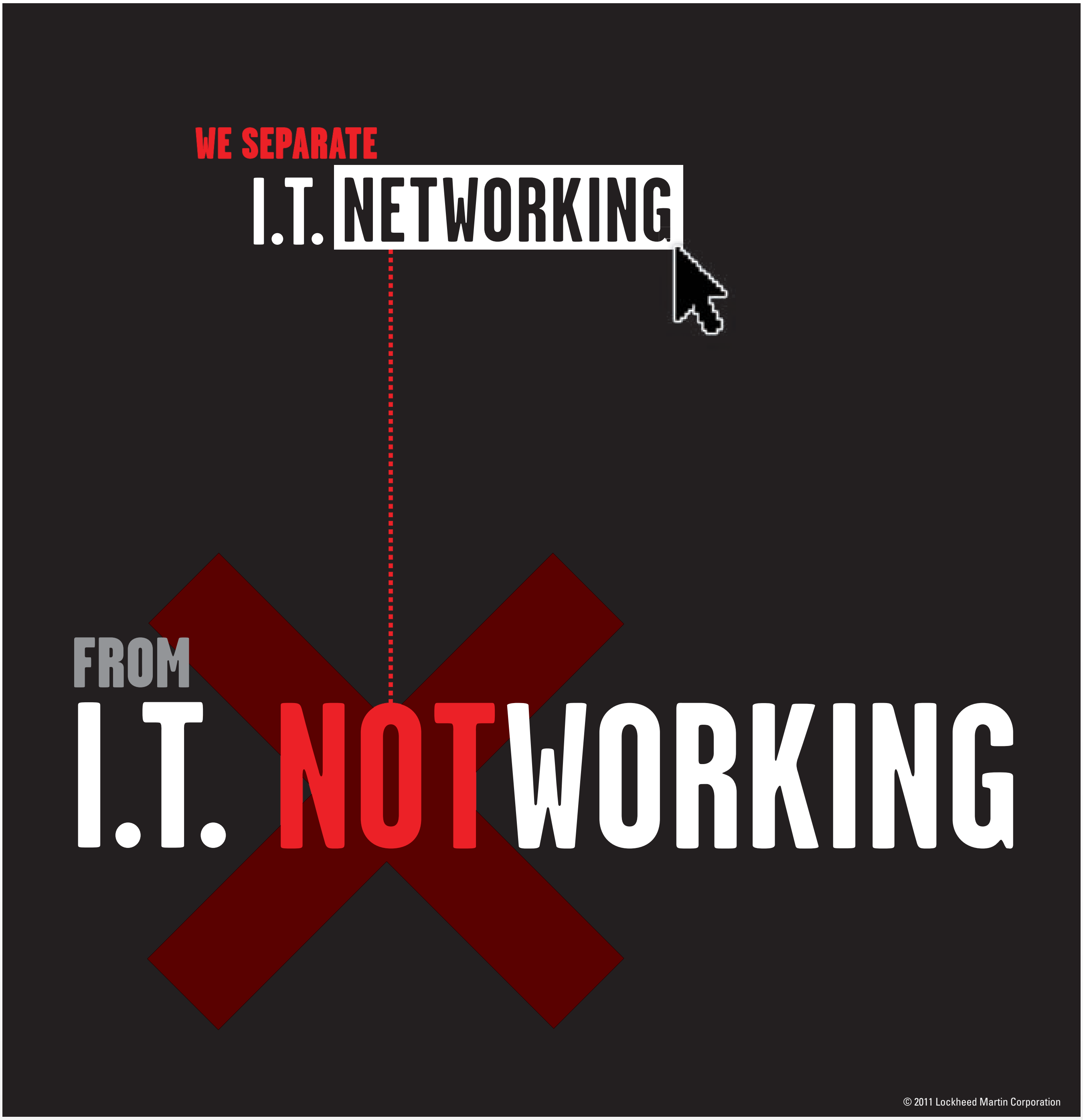
Taking perennials to the next level—adopting them on the scale of conventional crops—will require a significant scientific effort, however. Ed Buckler, a plant geneticist at Cornell University who plans to develop a perennial version of corn, thinks it will take five years to identify the genes responsible for the trait and another decade to breed a viable strain. "Even using the highest-technology approaches available, you're talking almost certainly 20 years from now for perennial maize," Glover says.

Scientists have been accelerating the development of perennials by using advanced genotyping technology. They can now quickly analyze the genomes of plants with desirable traits to search for associations between genes and those traits. When a first generation of plants produces seeds, researchers sequence young plants directly to find the handful out of thousands that retain those traits (rather than waiting for them to grow to adulthood, which can take years).

Once perennial alternatives to annual crops are available, rolling them out could have a big impact on carbon emissions. The key is their root systems, which would sequester, in each cubic meter of topsoil, an amount of carbon equivalent to 1 percent of the mass of that dirt. Douglas Kell, chief executive of the U.K.'s Biotechnology and Biological Sciences Research Council, has calculated that replacing 2 percent of the world's annual crops with perennials each year could remove enough carbon to halt the increase in atmospheric carbon dioxide. Converting all of the planet's farmland to perennials would sequester the equivalent of 118 parts per million of carbon dioxide—enough, in other words, to pull the concentration of atmospheric greenhouse gases back to preindustrial levels.

—Christopher Mims

COURTESY OF JIM RICHARDSON


WE SEPARATE
I.T. NETWORKING
FROM
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ENERGY

Liquid Fuel for Electric Cars

A new type of battery could replace fossil fuels with nanotech crude

BETTER BATTERIES are the key to electric cars that can drive for hundreds of miles between rechargings, but progress on existing technology is annoyingly incremental, and breakthroughs are a distant prospect. A new way of organizing the guts of modern batteries, however, has the potential to double the amount of energy such batteries can store.

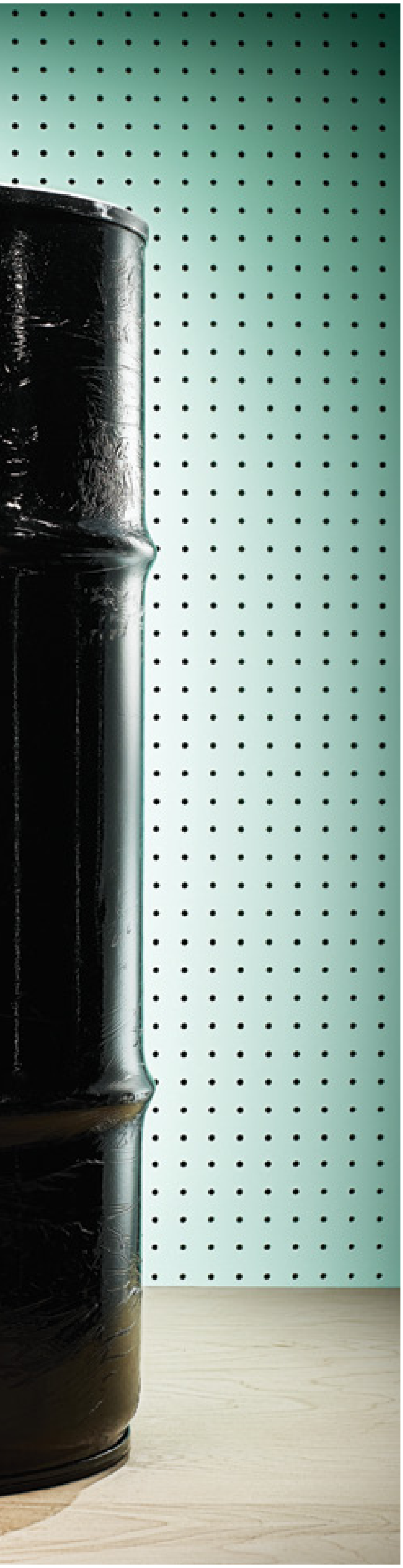
The idea came to Massachusetts Institute of Technology professor Yet-Ming Chiang while he was on sabbatical at A123 Systems, the battery company he co-founded in 2001. What if there was a way to combine the best characteristics of so-called flow batteries, which push fluid electrolytes through the cell, with the energy density of today's best lithium-ion batteries, the kind already in our consumer electronics?

Flow batteries, which store power in tanks of liquid electrolyte, have poor energy density, which is a measure of how much energy they can store. Their one advantage is that scaling them up is simple: you just build a bigger tank of energy-storing material.

Chiang and his colleagues constructed a working prototype of a battery that is as energy dense as a traditional lithium-ion battery but whose storage medium is essentially fluid, like a flow battery. Chiang calls it "Cambridge crude"—a black slurry of nanoscale particles and grains of energy-storing metals.

If you could visualize Cambridge crude under an electron microscope, you would see dust-size particles made of the same materials that make up the negative and positive electrodes in many lithium-ion batteries, such as lithium cobalt oxide (for the positive electrode) and graphite (for the negative one).

In between those relatively large particles, suspended in a liquid, would be the nanoscale particles made of carbon that are the secret sauce of this innovation. Clumping together into a spongelike network, they form "liquid wires" that connect the larger grains of the battery, where ions and electrons are stored. The result is a liquid that flows, even as its nanoscale components



constantly maintain pathways for electrons to travel between its grains of energy-storage medium.

"It's really a unique electrical composite," Chiang says. "I don't know of anything else that is like it."

The fact that the working material of the battery can flow has raised some interesting possibilities, including the idea that cars equipped with these batteries could drive into a service station and fill up on Cambridge crude to replace their charge. Chiang's collaborator on the project, W. Craig Carter of M.I.T., proposes that users might be able to switch out something resembling a propane tank filled with electrolyte rather than recharging at an outlet.

Transferring charged electrolyte into and out of his batteries is not the first commercial application that Chiang is pursuing, however. Along with Carter and entrepreneur Throop Wilder, he has already founded a new company, called 24M Technologies, to bring the team's work to market. Carter and Chiang are guarded about what the company will release first, but they emphasize the suitability of these batteries for grid-storage applications. Even a relatively small amount of storage can have a significant impact on the performance of intermittent energy sources such as wind and solar, Chiang says. Utility-scale batteries based on his design would have at least 10 times the energy density of conventional flow batteries, making them more compact and potentially cheaper.

Cambridge crude has a long way to go before it can be commercially viable, however. "A skeptic may say that this new design offers significantly more challenging problems to solve than benefits a potential solution may offer," says the head of a major research university's energy-storage program, who spoke on condition of anonymity so as not to offend a colleague. All the extra machinery required to pump the fluid through the battery's cells adds unwanted mass to the system. "The weight and volume of the pumps, storage cylinders, tubes, and the extra needed weight and volume of the electrolyte and carbon additives could make [the technology heavier than] the state of the art." These batteries may also not be as stable, across time and many cycles of charging and discharging, as conventional lithium-ion batteries.

A more fundamental issue is that charge times for these new batteries would be slower—two to four times slower, Carter says, than conventional ones. This creates a problem for cars, which require rapid transfers of power. One work-around could be pairing it with a conventional battery or an ultracapacitor, which can discharge its energy in a matter of seconds, to buffer transfers during braking and acceleration.

The new design has promise, however. A system that stores energy in "particulate fluids" should be compatible with almost any battery chemistry, says Yury Gogotsi, a materials engineer at Drexel University, making it a multiplier on future innovations in this area. "It opens up a new way of designing batteries," Gogotsi says. *—Christopher Mims*

MEDICINE

Nano-Size Germ Killers

Tiny knives could be important weapons against superbugs

DRUG-RESISTANT TUBERCULOSIS IS ROARING through Europe, according to the World Health Organization. Treatment options are few—antibiotics do not work on these highly evolved strains—and about 50 percent of people who contract the disease will die from it. The grim situation mirrors the fight against other drug-resistant diseases such as MRSA, a staph infection that claims 19,000 lives in the U.S. every year.

Hope comes in the form of a nanotech knife. Scientists working at IBM Research–Almaden have designed a nanoparticle capable of utterly destroying bacterial cells by piercing their membranes.

The nanoparticles' shells have a positive charge, which binds them to negatively charged bacterial membranes. "The particle comes in, attaches, and turns itself inside out and drills into the membrane," says Jim Hedrick, an IBM materials scientist working on the project with collaborators at Singapore's Institute of Bioengineering and Nanotechnology. Without an intact membrane, the bacterium shrivels away like a punctured balloon. The nanoparticles are harmless to humans—they do not touch red blood cells, for instance—because human cell membranes do not have the same electrical charge that bacterial membranes do. After the nanostructures have done their job, enzymes break them down, and the body flushes them out.

Hedrick hopes to see human trials of the nanoparticles in the next few years. If the approach holds up, doctors could squirt nanoparticle-infused gels and lotions onto hospital patients' skin, warding off MRSA infections. Or workers could inject the particles into the bloodstream to halt systemic drug-resistant organisms, such as streptococci, which can cause sepsis and death. Even if it succeeds, such a treatment would have to overcome any unease over the idea of nanotech drills in the bloodstream. But the nastiest bacteria on the planet won't succumb easily. *—Elizabeth Svoboda*

The Machine That Would Predict the Future

If you dropped all the world's data into a black box, could it become a crystal ball that would let you see the future—even test what would happen if you chose A over B? One researcher thinks so, and he could soon get a billion euros to build it

By David Weinberger

In the summer and fall of last year, the Greek financial crisis tore at the seams of the global economy. Having run up a debt that it would never be able to repay, the country faced a number of potential outcomes, all unpleasant. Efforts to slash spending spurred riots in the streets of Athens, while threats of default rattled global financial markets. Many economists argued that Greece should leave the euro zone and devalue its currency, a move that would in theory help the economy grow. "Make no mistake: an orderly euro exit will be hard," wrote New York University economist Nouriel Roubini in the *Financial Times*. "But watching the slow disorderly implosion of the Greek economy and society will be much worse."

No one was sure exactly how the scenario would play out, though. Fear spread that if Greece were to abandon the euro, Spain and Italy might do the same, weakening the central bond of the European Union. Yet the *Economist* opined that the crisis would "bring more fiscal-policy control from Brussels, turning the euro zone into a more politically integrated club." From these consequences would come yet further-flung effects. Migrants heading into the European Union might shift their travel patterns into a newly affordable Greece. A drop in tourism could limit the spread of infectious disease. Altered trade routes could disrupt native ecosystems. The question itself is simple—Should Greece drop the euro?—but the potential fallout is so far-reaching and complex that even the world's sharpest minds found themselves unable to grasp all the permutations.

Questions such as this one are exactly what led Dirk Helbing, a physicist and the chair of sociology at the Swiss Federal Institute of Technology Zurich, to propose a €1-billion computing system that would effectively serve as the world's crystal ball.

Photograph by Dan Saelinger


SIGNS
POINT TO
YES

David Weinberger is a senior researcher at Harvard University's Berkman Center for Internet and Society and co-director of the Harvard Library Innovation Laboratory at Harvard Law School. His latest book is *Too Big to Know,* which is being published in January 2012.

Helbing's system would simulate not just one area of finance or policy or the environment. Rather it would simulate everything all at once—a world within the world—spitting out answers to the toughest questions policy makers face. The centerpiece of this project, the Living Earth Simulator, would attempt to model global-scale systems—economies, governments, cultural trends, epidemics, agriculture, technological developments, and more—using torrential data streams, sophisticated algorithms, and as much hardware as it takes. The European Commission was so moved by Helbing's pitch that it chose his project as the top-ranked of six finalists in a competition to receive €1 billion.

The system is the most ambitious expression of the rise of "big data," a trend that is striking many scientists as being on a par with the invention of the telescope and microscope. The exponential growth of digitized information is bringing together computer science, social science and biology in ways that let us address questions we just otherwise could not have posed, says Nicholas Christakis, a social scientist and professor of medicine at Harvard University. As an example, he points to the ubiquity of mobile phones that create oceans of information about where individuals are going, what they are buying, and even traces of what they are thinking. Combine that with other kinds of data—genomics, economics, politics, and more—and many experts believe we are on the cusp of opening up new worlds of inquiry.

"Scientific advance is often driven by instrumentation," says David Lazer, an associate professor in the College of Computer and Information Science at Northeastern University and a supporter of Helbing's project. Tools attract the tasks, or as Lazer puts it: "Science is like the drunk looking for his keys under the lamppost because the light is better there." For Helbing's supporters, the ranks of which include dozens of respected scientists all over the world, €1 billion can buy a pretty bright light.

Many scientists are not convinced of the need to gather the world's data in a centralized collection, though. Better, they argue, to form data clouds on the Internet, connected by links to make them useful to all. A shared data format will give more people the opportunity to poke around through the data, find hidden connections and create a marketplace of competing ideas.

NEXT TOP MODEL

FINDING CORRELATIONS in sets of data is nothing out of the ordinary for modern science, even if those sets are now gigantic and the correlations span astronomical distances. For example, researchers have amassed so much anonymized data about human behavior that they have begun to unravel the complex behavioral and environmental factors that trigger "diseases of behavior" such as type 2 diabetes, says Alex Pentland, director of the Massachusetts Institute of Technology's Human Dynamics Laboratory. He says that mining big data this way makes the seminal Framingham study of cardiovascular disease—which, starting in 1948 followed 5,209 people—look like a focus group study.

Yet Helbing's FuturICT Knowledge Accelerator and Crisis-Relief System, as it's formally known, goes beyond data mining. It will include global Crisis Observatories that will search for nascent problems such as food shortages or emerging epidemics, as well as a Planetary Nervous System that aggregates data from sensor systems spread around the globe. But the heart of the FuturICT project is the Living Earth Simulator, an effort to model the myriad social, biological, political and physical forces at work in the world and use them to gain insight into the future.

Models have been with us for generations. In 1949 Bill Phillips, an engineer and economist from New Zealand, unveiled a model of how the U.K. economy worked that he had constructed out of plumbing supplies and a cannibalized windshield-wiper motor. Colored water simulated the flow of income based on "what if" adjustments in consumer spending, taxes and other economic activities. Although it is of course primitive by today's standards, it expresses the basics of modeling: stipulate a set of relations among factors, feed in data, watch the outcome. If the predictions are off, that itself becomes valuable information that can be used to refine the model.

Our society could no more function without models than without computers. But can you add enough pipes and pumps to model not only, say, the effect of volcano eruptions on short-term economic growth but also the effect of that change on all the realms of human behavior it touches, from education to the distribution of vaccines? Helbing thinks so. His confidence comes in part from his success modeling another complex system: highway traffic. By simulating the flow of vehicles on a computer, he and his colleagues came up with a model that showed (again, on a computer) that you could end stop-and-go delays by reducing the distance between moving vehicles. (Unfortunately, the distance is so small that it would require cars driven by robots.) Likewise, Helbing describes a project he consulted on that modeled the movement of pedestrians during the hajj in Mecca, resulting in a billion dollars of street and bridge rejiggering to prevent deaths from trampling. Helbing sees his FuturICT system as, in essence, a scaled-up elaboration of these traffic models.

Yet this type of agent-based modeling works only in a very narrow set of circumstances, according to Gary King, director of the Institute for Quantitative Social Science at Harvard. In the case of a highway or the hajj, everyone is heading in the same direction, with a shared desire to get where they are going as quickly and safely as possible. Helbing's FuturICT system, in contrast, aims to model systems in which people are acting for the widest

IN BRIEF

Researchers plan to build a computing system that would model the entire world to predict the future.

The project would be powered by the enormous data streams now available to researchers.

Yet models are not perfect; many researchers think they will never be able to capture the world's complexities.

A better knowledge machine may arise out of Web-like principles such as interconnection and argument.

PROP STYLING BY LAURIE RAAB, FOR HALLEY RESOURCES (*preceding pages*) variety of reasons (from selfish to altruistic); where their incentives may vary widely (getting rich, getting married, staying out of the papers); where contingencies may erupt (the death of a world leader, the arrival of UFOs); where there are complex feedback loops (an expert's financial model brings her to bet against an industry, which then panics the market); and where there are inputs, outputs and feedback loops from related models. The economic model of a city, for example, depends on models of traffic patterns, agricultural yields, demographics, climate and epidemiology, to name a few.

Beyond the problem of sheer complexity, scientists raise a number of interrelated challenges that such a comprehensive system would have to overcome. To begin with, we don't have a good theory of social behavior from which to start. King explains that when we have a solid idea of how things work—in physical systems, for example—we can build a model that successfully predicts outcomes. But whatever theories of social behavior we do have fall far short of the laws of physics in predictive power.

Nevertheless, King points to another possibility: if we have enough data, we can build models based on some hints about what creates regularities, even if we don't know what the laws are. For example, if we were to record the temperature and humidity at each point over the globe for a year, we could develop fairly accurate weather forecasts without any understanding of fluid dynamics or solar radiation.

We have already begun to use data to tease out some of these regularities in human systems, says Albert-László Barabási, director of the Center for Complex Network Research at Northeastern University and an adviser to the project. For example, Barabási and his colleagues recently unveiled a model that predicts with 90 percent accuracy where people will be at 5 P.M. tomorrow based purely on their past travel patterns. This knowledge does not assume anything about psychology, or technology, or the economy. It just looks at past data and extrapolates from there.

Yet sometimes the volume of data needed to make these approaches work dwarfs our capabilities. To get the same accuracy in a problem that requires you to consider 100 different interacting factors as you would in a two-dimensional problem, the number of data points required goes up into the number-of-stars-in-the-universe range, according to Cosma Shalizi, a statistician at Carnegie Mellon University. He concludes that unless you resign yourself to using simple models that fail to capture the full complexity of social behavior, "getting good models from data alone is hopeless."

FuturICT will not just rely on one model, however complex. Helbing says it will combine "computer science, complexity science, systems theory, social sciences (including economics and political sciences), cognitive science" and other fields. Yet combining models also creates problems of exploding complexity. "Let's say weather and traffic each have 10 outcomes," King says. "And now you want to know about both. So how many things do we need to know? It's not 20, it's 100. That doesn't make it hopeless. It just means the data requirements go up very quickly."

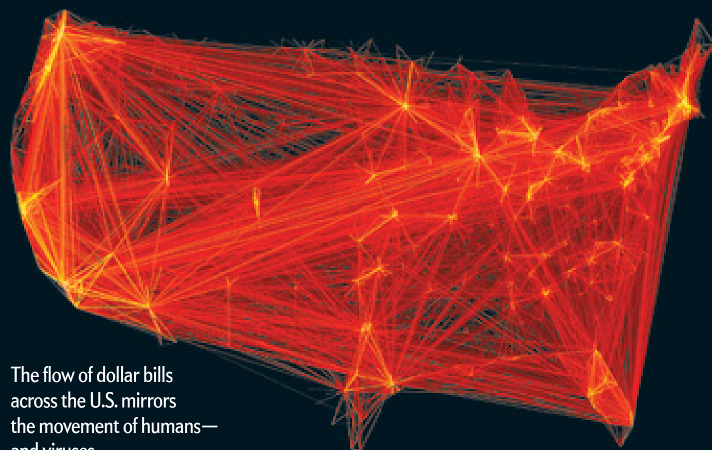
To further add to the challenge, news of a model's conclusions can alter the situation it is modeling. "This is the big scientific question," says Alessandro Vespignani, director of the Center for Complex Networks and Systems Research at Indiana University and the project's lead data planner. "How can we develop models that include feedback loops or real-time data monitors that let us continuously update our algorithms and get new predictions" even as the predictions affect their own conditions?

The models also have to be incredibly intricate and particular. For example, if you ask an economic model if your city should reclaim some land and if the model does not take account how that decision affects the food chain, it can generate a result that might be good economics but disastrous for the environment. With 10 million species, simply learning which one eats what is a daunting task. Further, relevant variances in food do not stop at the species level. Jesse Ausubel, an environmental scientist at the Rockefeller University, points out that by analyzing the DNA of the contents of the stomachs of bats, we can know for sure exactly what bats eat. But the food source of bats in a specific cave might be different from the food source of bats of the same species a few miles away. Without crawling through the guano-coated particularities cave by cave, experts relying on interrelated models may encounter unreliable and cascading effects.

PUBLIC HEALTH APPLICATIONS

Disease Follows the Money

Imagine a novel in which a deadly flu virus emerges. Where will it spread? Physicists and epidemiologists have begun to tap enormous data streams to make predictions about how a pandemic might play out—and what can be done to stop it. Scientists took data from the Where's George project, which tracks the location of millions of dollar bills as they move across the U.S., to model how 2009's H1N1 flu virus would likely spread. Other researchers used air and land traffic patterns in the same way. The studies demonstrated both the promise and problems of big data: they accurately predicted *where* the flu would spread, but they severely undercounted the number of people who would end up infected.



The flow of dollar bills across the U.S. mirrors the movement of humans—and viruses.

FROM "THE STRUCTURE OF BORDERS IN A SMALL WORLD," BY C. THIEMANN, F. THEIS, D. GRADY, R. BRUNE AND D. BROCKMANN, IN *PLOS ONE*, VOL. 5, NO. 11; 2010

It is not at all clear that human brains will be capable of understanding why the supercomputers have come up with the answers they have.

So while in theory we might be able to construct models of complicated phenomena even when we do not have any underlying laws on which to build them, the practical difficulties quickly turn exponential. There is always another layer of detail, always another factor that may prove critical in the final accounting; without a prior understanding of how humans operate, we cannot know when our accounting is final.

Big data have given rise to many successes in genomics and astrophysics, but success in one field may not be evidence that we can succeed when fields are interdependent in highly complex ways. Perhaps we can make stepwise progress. Or there may be a natural limit to the power of models for systems as complex as those that involve human activity. Human systems, after all, are subject to the two hallmarks of unpredictability: black swans and chaos theory.

KNOWLEDGE WITHOUT UNDERSTANDING

ON DECEMBER 17, 2010, Mohamed Bouazizi, a street vendor in the small Tunisian town of Sidi Bouzid, set himself on fire in a protest against the local culture of corruption. That singular act set into motion a popular revolution that burned across the Arab world, leading to uprisings that overthrew decades of dictatorial rule in Egypt, Libya and beyond, upending forever the balance of power in the world's most oil-rich region.

What model would have been able to foresee this? Or the attacks of September 11, 2001, and the extent of their effects? Or that the Internet would go from an obscure network for researchers to a maker and breaker of entire industries? This is the black swan problem popularized by Nassim Nicholas Taleb in his 2007 best seller of the same name. "The world is always more complex than models," Ausubel says. "It's always something."

What's worse, the social, political and economic systems that Helbing wants to understand are not merely complex. They are chaotic. Each depends on hundreds of unique factors, all intricately interrelated and profoundly affected by the state from which they started. Everything happens for a reason in a chaotic system, or, more exactly, everything happens for so many reasons that events are unpredictable except in the broadest of strokes. For example, Jagadish Shukla, a climatologist at George Mason University and president of the Institute of Global Environment and Society, told me that while we can now forecast the weather five days ahead, "we may not be able to get beyond day 15. [No] matter how many sensors you put in place, there will still be some errors in the initial conditions, and the models we use are not perfect." He adds, "The limitations are not technological. They are the predictability of the system."

Shukla is careful to distinguish weather from climate. We may not be able to predict whether it will rain in the afternoon exactly 100 years from now, but we can with some degree of reliability predict what the average ocean temperature will be. "Even though climate is a chaotic system, it still does have predictability," Shukla says. And so it would be for Helbing's models. "Detailed financial-market moves are probably much less predictable than weather," Helbing wrote in an e-mail, "but the fact that a financial meltdown would happen sooner or later could be derived from certain macroeconomic data (for example, that consumption in the U.S. grew bigger than incomes over many years)." But we don't need a set of supercomputers, galaxies of data and €1 billion to know that.

If the aim is to provide scientifically based advice to policy makers, as Helbing emphasizes when justifying the expense, some practical issues arise. For one thing, it is not at all clear that human brains will be capable of understanding why the supercomputers have come up with the answers that they have. When the model is simple enough—say, a hydraulic model of the British economy—we can backtrack through a model run and realize that the drawdown of personal savings accounts was an unexpected effect of raising taxes too quickly. But sophisticated models derived computationally from big data—and consequently tuned by feeding results back in—might produce reliable results from processes too complex for the human brain. We would have knowledge but no understanding.

When I asked Helbing about this limitation, he paused before saying he thought it likely that human-understandable general principles and equations would probably emerge because they did when he studied traffic. Still, the intersection of financial systems, social behaviors, political movements, meteorology and geology is orders of magnitude more complex than three lanes of traffic moving in the same direction. So humans may not be able to understand why the model predicts disaster if Greece goes off the euro.

Without understanding why a particular course of action is the best one, a president or prime minister would never be able to act on it—especially if the action seems ridiculous. Victoria Stodden, a statistician at Columbia University, imagines a policy maker who reads results from the Living Earth Simulator and announces, "To pull the world out of our economic crisis, we must set fire to all the world's oil wells." That will not be actionable advice if the policy maker cannot explain why it is right. After all, even with scientists virtually universally aligned about the danger of climate change, policy makers refuse to prepare for the future predicted by every serious environmental model.

NERDS ARGUING WITH NERDS

THESE AND OTHER practical problems arise because FuturICT as Helbing currently describes it assumes that such a large, complex effort requires a central organization to take charge. Helbing would oversee a global project that would assemble the hardware, collect data and return results.

It's not what John Wilbanks, vice president of science at Creative Commons, would do. Wilbanks shares Helbing's enthusiasm for big data. But his instincts hew to the Internet, not the institution. He is a leading figure in an ongoing project to organize various "data commons" that anyone can make use of. The aim is to let the world's scientists engage in an open market of ideas, models and results. It is the opposite approach to planning out a formalized institution with organized inputs and high-value outputs.

The two approaches focus on different values. A data commons might not have the benefits of up-front, perfect curation that a closed system has, but Wilbanks believes it more than makes up for that in "generativity," a term from Jonathan Zittrain's 2008 *The Future of the Internet:* "a system's capacity to produce unanticipated change through unfiltered contributions from broad and varied audiences." The Web, for example, allows everyone to participate, which is why it is such a powerful creative engine. In Wilbanks's view, science will advance most rapidly if scientists have access to as much data as possible, if that information is open to all, is easy to work with, and can be pulled together across disciplines, institutions and models.

Over the past few years a new "language" for data has emerged that makes Wilbanks's dream far more plausible. It grows out of principles enunciated in 2006 by Tim Berners-Lee, inventor of the World Wide Web. In this "linked data" format, information comes in the form of simple assertions: *X* is related to *Y* in some specified way; the relation can be whatever the person releasing the data wants. For example, if Creative Commons wanted to release its staffing information as linked data, it would make it available in a series of "triples": [John Wilbanks] [leads] [Science at Creative Commons], [John Wilbanks][has an e-mail address of] [johnsemail@creativecommons.org], and so forth.

Further, because many John Wilbanks live in the world and because "leads" has many meanings, each element of these triples would include a Web link that points at an authoritative or clarifying source. For example, the "John Wilbanks" link might point to his home page, to the page about him at CreativeCommons.org or to his Wikipedia entry. "Leads" might point to a standard vocabulary that defines the type of leadership he provides.

This linked structure enables researchers to connect data from multiple sources without having first to agree on a single abstract model that explains the relations among all the pieces. This lowers the cost of preparing the data for release. It also increases the value of the data after they have been released.

A linked-data approach increases the number of eyeballs that could in theory pay attention to any particular data set, thus increasing the likelihood that someone will stumble across an interesting signal. More hypotheses will be tested, more models tried. "Your nerds and my nerds need to have arguments," Wilbanks says. "They need to argue about whether the variables and the math in the models are right and whether the assumptions are right." The world is so chaotic that our best chance to make sense of it—to catch a financial meltdown in time—is to get as many nerds poking at it as we can. For Wilbanks and his tribe, making the data open and interoperable is the first step—the transformative step. Among the groups entering the fray certainly will be institutions that have assembled great minds and built sophisticated models. But the first and primary condition for the emergence of the truth is the fray itself. Nerds arguing with nerds.

Wilbanks and Helbing both see big data as transformative, and both are hopeful that far more social behavior can be understood scientifically than we thought just a few years ago. When Helbing is not trying to persuade patrons by painting a picture of how the Living Earth Simulator will avert national bankruptcies and global pandemics—as Barabási observes, "If you want to convince politicians, you have to talk about the outcomes"—he acknowledges that FuturICT will support multiple models that compete with one another. Further, he is keen on gathering the biggest collection of big data in history and making almost all of it public. (Some will have to stay private because it comes under license from commercial providers or because it contains personal information.)

Nevertheless, the differences are real. Helbing and his data architect, Vespignani, do not stop with the acknowledgment that the FuturICT institution will support multiple models. "Even weather forecasts are made with multiple models," Vespignani says. Then he adds, "You combine them and get a statistical inference of what the probabilistic outcome will be." For Helbing and him, the value is in this convergence toward a single answer.

The commons view also aims at convergence toward truth, of course. But as a networked infrastructure, it acknowledges and even facilitates fruitful disagreement. Scientists can have different models, different taxonomies, different nomenclatures, but they can still talk with one another because they can follow their shared data's links back to some known anchor on the Internet or in the real world. They can, that is, operate on their own and yet still communicate and even collaborate. The differences won't resolve into a single way of talking about the world because—Wilbanks argues—there may be differences of culture, starting point, even temperament. The data-commons approach recognizes, acknowledges and even embraces the persistence of difference.

WHAT KNOWLEDGE IS

THE OBVIOUS QUESTION is the practical one: Which approach is going to work better, where "working better" means advancing the state of the science and producing meaningful (and accurate) answers to hard questions about the future?

The answer may come down to a disagreement about the nature of knowledge itself. We have for a couple of millennia in the West thought of knowledge as a system of settled, consistent truths. Perhaps that exhibits the limitations of knowledge's medium more than of knowledge itself: when knowledge is communicated and preserved by writing it in permanent ink on paper, it becomes that which makes it through institutional filters and that which does not change. Yet knowledge's new medium is not a publishing system so much as a networked public. We may get lots of knowledge out of our data commons, but the knowledge is more likely to be a continuous argument as it is tugged this way and that. Indeed, that is the face of knowledge in the age of the Net: never fully settled, never fully written, never entirely done.

The FuturICT platform hopes to build a representation of the world sufficiently complete that we can ask it questions and rely on its answers. Linked data, on the other hand, arose (in part) in contrast to the idea that we can definitively represent the world in logical models of all the many domains of life. Knowledge may come out of the commons, even if that commons is not itself a perfect representation of the world.

Unless, of course, the messy contention of ideas—nerds arguing with nerds—is a more fully true representation of the world. SA

MORE TO EXPLORE

The Semantic Web. Tim Berners-Lee, James Hendler and Ora Lassila in *Scientific American,* Vol. 284, No. 5, pages 34–43; May 2001.

Too Big to Know: Rethinking Knowledge Now That the Facts Aren't the Facts, Experts Are Everywhere, and the Smartest Person in the Room Is the Room. David Weinberger. Basic Books (in press). **www.hyperorg.com/blogger**

The FuturICT Project: **www.futurict.eu**

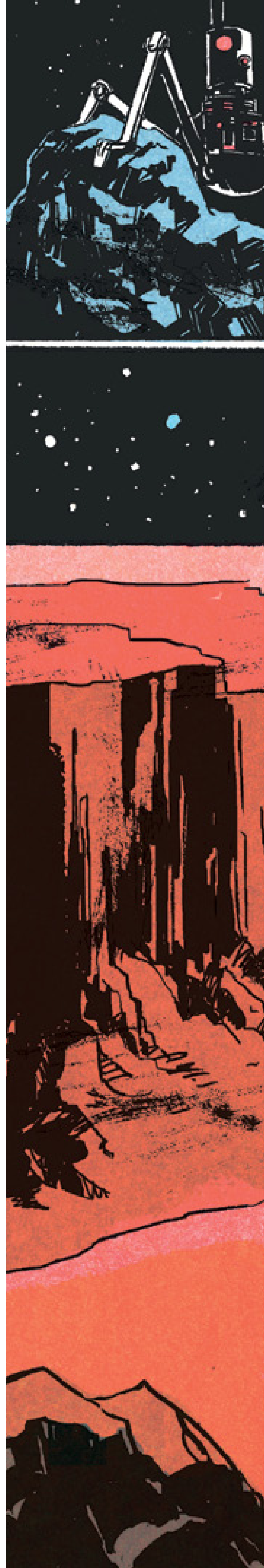
SCIENTIFIC AMERICAN ONLINE
What big data means for knowledge: **ScientificAmerican.com/dec2011/big-data**

SPACE EXPLORATION

THIS WAY TO MARS

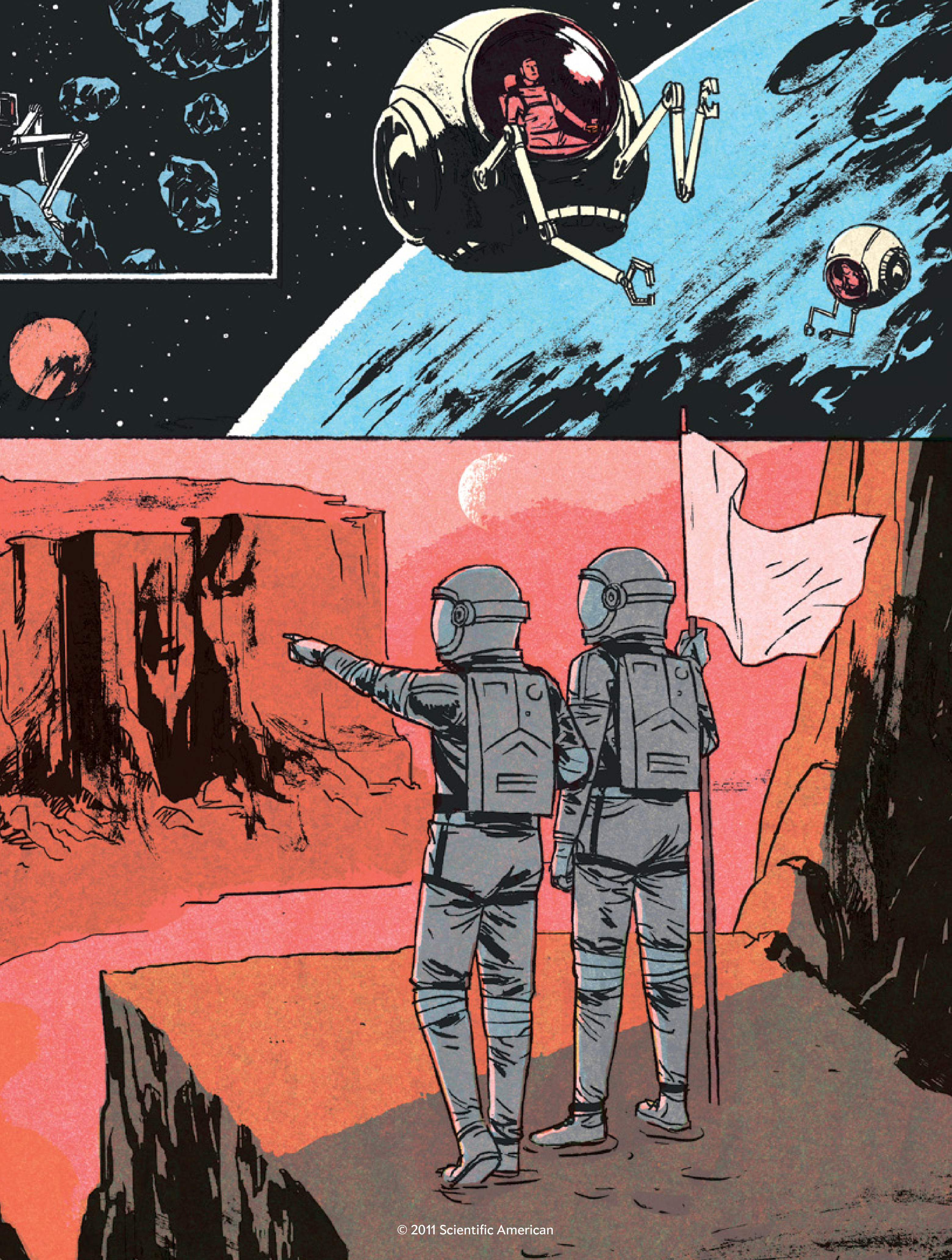
By adapting ideas from robotic planetary exploration, the human space program could get astronauts to asteroids and Mars cheaply and quickly

By Damon Landau and Nathan J. Strange



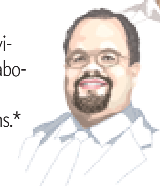
Being there: An asteroid, Mars's moon Phobos and the Red Planet's surface are all on the proposed itinerary. The moons are exaggerated in this artist's fanciful conception.

Illustration by Patrick Leger



Damon Landau is an outer-planet mission analyst at the NASA Jet Propulsion Laboratory (JPL). He helped to design the trajectory for NASA's recently launched Juno mission to Jupiter and worked on the agency's survey of near-Earth asteroids that astronauts might visit.

Nathan J. Strange is a JPL mission architect. He was on the navigation team for the Cassini-Huygens mission to Saturn and collaborated on the design of the gravity-assist tour of Saturn's moons. He has worked on technical blueprints for future human missions.*



IN OCTOBER 2009 A SMALL GROUP OF ROBOTIC SPACE EXPLORAtion geeks decided to venture out of our comfort zone and began brainstorming different approaches to flying people into space. We were spurred into action when the Augustine commission, a blue-ribbon panel that President Barack Obama set up earlier that year to review the space shuttle and its intended successor, reported that "the U.S. human spaceflight program appears to be on an unsustainable trajectory." Having worked in an exciting robotic exploration program that has extended humanity's reach from Mercury to the edge of the solar system, we wondered whether we might find technical solutions for some of NASA's political and budgetary challenges.

Ideas abounded: using ion engines to ferry up the components of a moon base; beaming power to robotic rovers on the Martian moon Phobos; attaching high-power Hall effect thrusters to the International Space Station (ISS) and putting it on a Mars cycler orbit; preplacing chemical rocket boosters along an interplanetary trajectory in advance so astronauts could pick them up along the way; using exploration pods like those in *2001: A Space Odyssey* rather than space suits; instead of sending astronauts to an asteroid, bringing a (very small) asteroid to astronauts at the space station. When we crunched the numbers, we found that electric propulsion—via an ion drive or related technologies—could dramatically reduce the launch mass required for human missions to asteroids and Mars.

It was like being back in the NASA of the 1960s, minus the cigarette smoke. We talked about what we can do and avoided getting mired in what we cannot. After our initial analysis, we put together a lunchtime seminar for our colleagues at the NASA Jet Propulsion Laboratory (JPL) that synthesized these notions and calculations. Throughout the following spring and summer we met other engineers and scientists who were interested in our approach and gave us ideas to make it better. We learned about experiments that people inside and outside NASA had been conducting: from tests of powerful electric thrusters to designs for lightweight, high-efficiency solar arrays. Our discussions have grown and become part of a larger groundswell of inventive thinking across the space agency and aerospace industry.

We have now combined the most promising proposals with tried-and-true strategies to develop a plan to send astronauts to the near-Earth asteroid 2008 EV5 as soon as 2024 as preparation for an eventual Mars landing. This approach is designed to fit within NASA's current budget and, crucially, breaks the overall task into a series of incremental milestones, giving the agency flexibility to speed up or slow down depending on funding. In a nutshell, the aim is to apply lessons from the robotic scientific exploration program to renew the human exploration one.

SMALL STEPS MAKE A GIANT LEAP

THE AUGUSTINE COMMISSION's report ignited a mighty political fight, culminating in the decision to delegate much of the task of launching astronauts into orbit to private companies [see "Jump-Starting the Orbital Economy," by David H. Freedman; SCIENTIFIC AMERICAN, December 2010]. NASA can now focus on

IN BRIEF

Space policy in the U.S. has gone through an upheaval. NASA has retired the shuttle, given up the Constellation program that was to have replaced it and outsourced orbital launches. It is supposed to return to what it does best—going where no one has gone before. But how?

The authors argue that engineers need to assume that the political process will continue to be unpredictable—and plan for it. They must design mission options that can be ramped up or down as circumstances change.

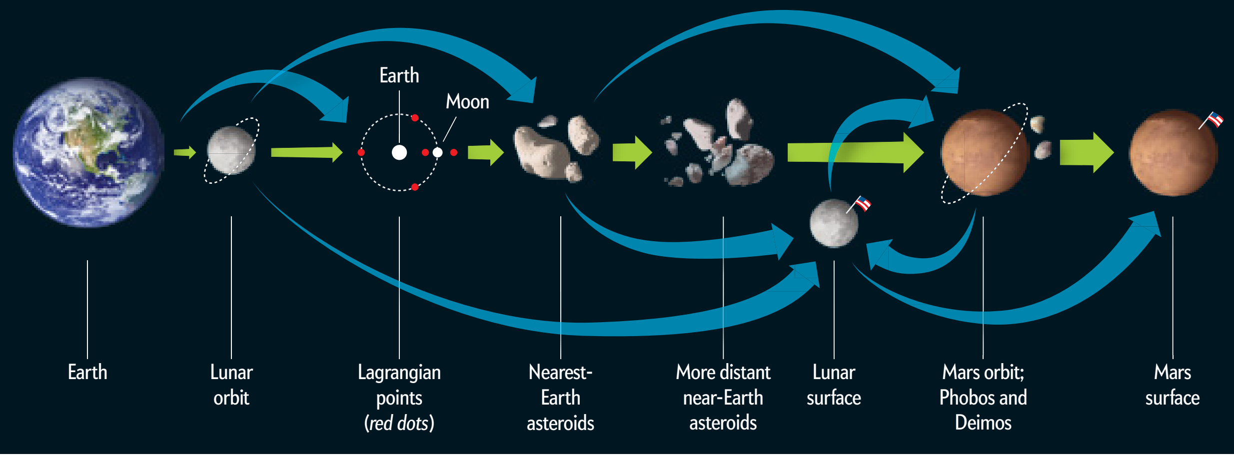
Deep-space vehicles propelled by ion drives can mount progressively more complicated expeditions to lunar orbit, near-Earth asteroids and eventually Mars.

The views expressed in this article are those of the authors, not NASA or JPL.

FLEXIBLE PATH

More Than One Way to Reach into Space

In the past the U.S. human space program took an all-eggs-in-one-basket approach: it focused on a specific target and a single system to get there. As of last year, it does things differently. It now has the broad goal of venturing into interplanetary space in progressively more complicated missions, such as the authors' proposed program (*green arrows*) and variants (*blue arrows*). The destinations are listed here in rough order of difficulty. Vehicles can be repurposed to reach different destinations, follow different sequences or use different technologies if technical problems arise or politicians fail to come through with the required funding.



MODIFIED FROM NASA'S REVIEW OF U.S. HUMAN SPACE FLIGHT PLANS COMMITTEE; NASA (*Earth, moon and Mars*)

transformative technology and push human exploration on to new frontiers. But how can the agency move forward without the political support and resources it enjoyed during the glory days of the Apollo moon landings?

The established approach in robotic exploration is incremental: develop a technology portfolio that enables increasingly ambitious missions to take place. Rather than relying on an all-or-nothing development path to a single target, the robotic exploration program makes use of novel combinations of technology to reach a variety of targets. To be sure, the robotic program has suffered its own mistakes and inefficiencies; nothing is perfect. At least it does not grind to a halt when the political winds change or when technological innovation lags. The human program can borrow from this strategy. It need not commence with "one giant leap" as with Apollo. It can embark on a series of modest steps, each building on the one before.

For some, the real lesson of robotic exploration might be that we should not send people at all. If NASA's only goal was scientific discovery, robotic probes would certainly be cheaper and lower risk. Yet NASA is tasked with more than just science; science is only one aspect of a broader human impulse to explore. Space exploration has wide appeal because of a desire for ordinary people to experience it firsthand someday. Robotic probes are just the first wave of solar system exploration. Government-funded human missions will be the second wave, and the third will be private citizens seeking their fortune and adventure in space. NASA's past investments developed the technology that is fueling today's commercial space race, with capsules launching to the space station and space planes jetting over the Mojave Desert [see "Blastoffs on a Budget," by Joan C. Horvath; Scientific American, April 2004]. NASA can now develop the technology that we will need to push deeper into the beyond.

FLEXIBILITY IS THE WATCHWORD

THREE BASIC PRINCIPLES govern the course we recommend. The first is the "flexible path" approach that the Augustine commission advocated and that President Obama and Congress accepted. This strategy replaces the old insistence on a fixed path from Earth to moon to Mars with an extensive selection of possible destinations. We would begin with nearby ones, such as the Lagrangian points (locations in space where an object's motion is balanced by gravitational forces) and near-Earth asteroids.

The flexible path calls for new vehicle technologies, notably electric propulsion. We propose using Hall effect thrusters (a type of ion drive) powered by solar panels. A similar system propelled the Dawn spacecraft to the giant asteroid Vesta and will, by 2015, carry it onward to the dwarf planet Ceres [see "New Dawn for Electric Rockets," by Edgar Y. Choueiri; Scientific American, February 2009]. Whereas traditional chemical rockets produce a powerful but brief blast of gas, electric engines fire a gentle but steady stream of particles. Electric power makes the engines more efficient, so they use less fuel. (Think space Prius.) Because the price of this greater efficiency is lower thrust, some missions can take longer. A common misperception is that electric propulsion is too slow for crewed spaceflight, but there are ways around that. The idea that emerged at our first brainstorming session was to use robotic electric propulsion tugs to place chemical boosters at key points in a trajectory like a trail of bread crumbs; once the trail is laid, astronauts can set out and pick up the boosters as they go along. In this way, missions get the fuel efficiency of electric propulsion while keeping the speed advantage of chemical propulsion.

Crucially, electric propulsion saves money. Because the ship does not need to lug around as much propellant, its total launch mass drops by 40 to 60 percent. To first order, the price tag of

Illustration by Pitch Interactive

space missions scales linearly with the launch mass. Thus, slimming the mass by half could cut the cost by a similar fraction.

Many space enthusiasts wonder why we would bother visiting an asteroid when Mars is everyone's favorite destination. Actually asteroids are the perfect targets for an incremental approach toward reaching Mars. Thousands are sprinkled through the gap between Earth and Mars, providing literal steppingstones into deep space. Because asteroids' gravity is so weak, landing on one takes less energy than reaching the surface of the moon or Mars. It is hard enough to mount a long interplanetary expedition—six to 18 months—without also having to develop elaborate vehicles to touch down and blast off again. Asteroid missions let us focus on what, in our estimation, is the most complex (and still unsolved) problem for humans ever to venture far from Earth: learning how to protect astronauts from the deleterious effects of zero gravity and space radiation [see "Shielding Space Travelers," by Eugene N. Parker; Scientific American, March 2006]. As NASA gains experience dealing with the hazards of deep space, it will be in a better position to design vehicles for Mars surface missions.

Several scientifically interesting asteroids could be visited by astronauts with flight times ranging from six months to a year and a half using a 200-kilowatt (kW) electric propulsion system, which is a reasonable advance over our present capability; the ISS currently has 260 kW of solar arrays installed. Such a mission would break the deep-space barrier, while taking a crucial step toward the two- to three-year flight times and 600-kW systems that would be needed for Mars exploration.

To get to an asteroid, NASA does not have to invent completely new systems for everything, as it did in the 1960s.

The second governing principle of our plan is that NASA does not have to invent completely new systems for everything as it did in the 1960s. Some systems, most notably zero-g and deep-space radiation protection, will require new research. Everything else can derive from existing spacefaring assets. The deep-space vehicle can be assembled by combining a few specialized elements. For instance, the structure, solar arrays and life-support systems could be adapted from designs that have been implemented on the space station. And many private companies and other nations' space agencies have expertise in these areas that NASA could tap.

The third principle is to design a program that can maintain forward momentum even if one component runs into problems or delays. This principle should be applied to the most debated component of the space policy adopted by Congress: the launch vehicle that will ferry the crew and exploration vehicles from the surface of Earth into orbit. Congress directed NASA to build a new heavy-lift rocket, the Space Launch System (SLS). As announced this past September, NASA plans to develop this vehicle in steps starting at roughly half the capacity of the Apollo Saturn V and working up to just beyond the full launch capability of that rocket. The first SLS launcher, plus the *Orion* capsule now in the works, could carry astronauts on three-week excursions to lunar orbit and the Lagrangian points but can take astronauts no farther without the development of a new system.

Fortunately, journeys to deep space do not need to wait for the SLS to be completed. Preparations could begin now with the development of the life-support and electric propulsion systems that will be needed for trips beyond the moon. By making these systems an early priority, even while the new rockets are still under development, NASA would be better able to refine details of the SLS design to make it better suited to deep-space missions. These components could even be designed to fit on commercial or international launchers and then assembled in orbit, just as the ISS and the *Mir* space station were. The use of existing rockets would generate momentum toward deep-space exploration. With the flexibility from a portfolio of options, NASA could fit more exploration into its increasingly limited budget.

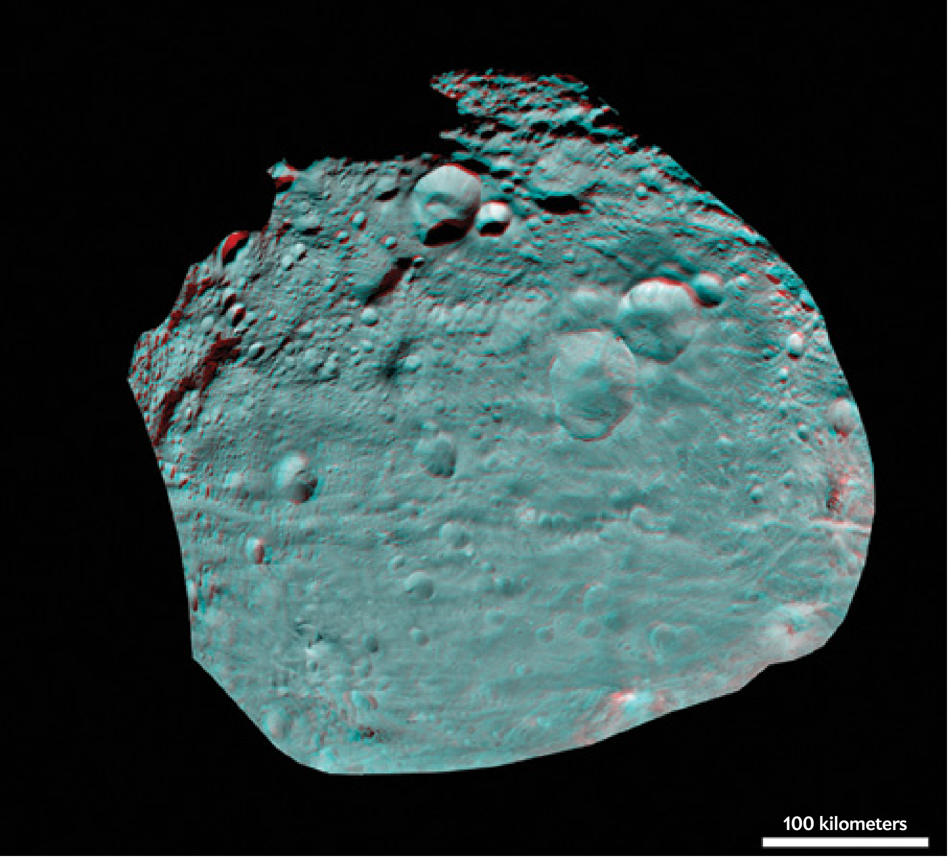
MISSION: 2008 EV5

In our plan, NASA's renaissance begins by constructing the means for people to travel between the planets—the deep-space vehicle. A solar-powered ion drive provides the oomph, and a new transit habitat provides a safe haven away from home. The most basic deep-space vehicle would consist of two modules that could both be lofted into low Earth orbit with a single launch of the smallest of NASA's new SLS rockets. Alternatively, three commercially available rockets could do the trick, two for the vehicle components and one with supplies for the trip.

The maiden voyage is, ironically, its most boring. For two years the ship, without crew, is remotely piloted to follow a slow spiral from low Earth orbit through the Van Allen radiation belts and up to a high Earth orbit—a trip that goes easy on propellant but is too long and radioactive for astronauts. Once the spaceship is poised on the outer edge of Earth's gravity well, just one push away from interplanetary space, it can undertake lunar flybys and other maneuvers to reshape the orbit for efficient departure. The astronauts then fly up from the ground on a conventional chemical booster.

For a test flight, astronauts steer the vehicle into an orbit that almost always remains above the south pole of the moon. From there they could control a fleet of robotic explorers and investigate the composition of ancient ice deposits in the forever-dark craters of the Aitken basin. Such a mission puts long-duration exploration through its paces with the safety of Earth just a few days away. After the crew returns to Earth, the deep-space vehicle remains in high Earth orbit, awaiting refueling and refurbishment for its first asteroid mission.

We have investigated a wide range of such missions. Some would take astronauts to small objects (less than 100 meters across) just beyond the moon and back to Earth in under six months. Others would venture to large objects (bigger than a kilometer) almost out to Mars and back in two years. Focusing only on an easier mission could stunt exploration by setting a dead end for technological capability. Conversely, striving for a harder mission could perpetually delay any meaningful exploration by setting targets too far out of reach. Our design baseline falls between these two extremes. It is a one-year round-trip that launches in 2024, with 30 days spent exploring asteroid 2008 EV5. This object, about 400 meters across, appears to be a type of asteroid of great interest to many planetary scientists—a type C carbonaceous asteroid, a possible relic from the formation of the solar system and perhaps representative of the original source of Earth's organic material.



Asteroid Vesta is currently being orbited by NASA's Dawn robotic spacecraft. The mission is remarkable for using hyperefficient ion engines, as human interplanetary missions someday could. (You can use red-blue glasses to view this image in 3-D.)

COURTESY OF NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

The most efficient way to get there is to use Earth's gravity for an old trick known as the Oberth effect. It is the reverse of the orbit-insertion maneuvers that robotic space probes routinely undertake. To prepare for it, mission controllers outfit the deep-space vehicle with a high-thrust chemical rocket stage, carried up from Earth by an electrically propelled resupply tug. After the stage is attached and the crew is onboard, the deep-space vehicle free-falls from the vicinity of the moon down to just above Earth's atmosphere to build up tremendous speed. Then, at just the right moment, the high-thrust stage fires, and the vehicle frees itself from Earth's grasp in a matter of minutes. This maneuver works best at the moment when the vehicle is traveling at top speed near Earth because the amount of energy the ship gains is proportional to how fast it is already traveling. The Oberth effect is an exception to the rule that ion drives are more efficient than chemical rockets; you need a lot of thrust, quickly, to take full advantage of the gravitational kick start from Earth, and only high-thrust rockets can provide it. Together the ion-propelled spiral and chemical-powered Oberth effect cut the amount of fuel it takes to escape Earth's gravity by 40 percent compared with an all-chemical system.

Once the astronauts escape Earth, the Hall effect thrusters turn on and steadily push the vehicle toward its destination. Because ion drive provides continuous thrust, it lends itself to flexibility. Mission planners can develop a robust set of abort trajectories should a malfunction occur at any point in the mission. (The Japanese robotic asteroid mission Hayabusa was able to recover from several mishaps because of its ion drive.) If technical or budgetary problems prevent us from getting the deep-space vehicle ready in time to reach the asteroid 2008 EV5, we can choose another target. Likewise, if we encounter technical difficulties, we will improvise. For instance, if high-performance propellants are too hard to store in deep space, we can switch to lower-performing propellants and revise the mission accordingly. Nothing in the mission is locked in.

THE PLUSES OF PODS

IN OUR PLAN, the astronauts have a month at the asteroid for exploration. Rather than donning space suits, they can take a lesson from deep-sea submersibles and use exploration pods. Space suits are basically big balloons, and an astronaut constantly fights air pressure for every little movement, making space walks hard work and limiting what can be accomplished. A pod with robotic manipulator arms not only alleviates this problem but also provides room to eat and rest. In a pod, an astronaut could zip around for several days at a time. NASA is already developing a Space Exploration Vehicle (SEV) that can be used as a pod at asteroids, and the same design could later be adapted for a surface rover for the moon and Mars.

The astronauts conduct a full survey, looking for unusual mineral outcrops and other promising places to dig for samples that might date to the earliest days of the solar system. NASA will want to send a crew that is half Indiana Jones and half Mr. Scott: astronauts with both the scientific background needed to spot precious samples hidden in the dust and the engineering background needed to fix any problems along the way.

When the month is up, the ion drive nudges the deep-space vehicle away from the asteroid and onto a six-month trajectory back home. A few days before reaching Earth, the crew climbs into a capsule, separates from the main ship and sets course to splash down. The empty deep-space vehicle remains on an orbit around the sun. It performs a flyby of Earth and continues thrusting with the ion drive to lower its energy with respect to the Earth-moon system, so that when it comes back to Earth a year later, it can use a lunar flyby to reenter high Earth orbit and await its next mission. Its ion drive and habitat module could be reused multiple times.

After several yearlong asteroid missions, incremental improvements to life-support systems and radiation shielding will pave the way to Mars. The first Mars mission might not actually touch down on the planet. Instead it will likely explore its two moons, Phobos and Deimos [see "To Mars by Way of Its Moons," by S. Fred Singer; Scientific American, March 2000]. Such an expedition is essentially an asteroid mission stretched out to a two-and-a-half-year round-trip. At first glance, it might seem silly to go all the way to Mars and not land on it, but landing would enormously complicate the mission. Missions to the Martian moons allow astronauts to become adept at traveling through interplanetary space before attempting the challenge

Breaking the Deep-Space Barrier

The authors' proposed new paradigm for human interplanetary exploration emphasizes flexibility and sustainability. Rather than one-shots like the Apollo moon landings and most previous interplanetary mission designs, NASA and its partners would build a deep-space vehicle that can be used and reused (employing lessons from the space shuttle and the International Space Station). It could be good to go by 2024. Assembling, testing and sending it on its way would be a multistage process. In between flights, the ship would be parked in a high-altitude orbit.

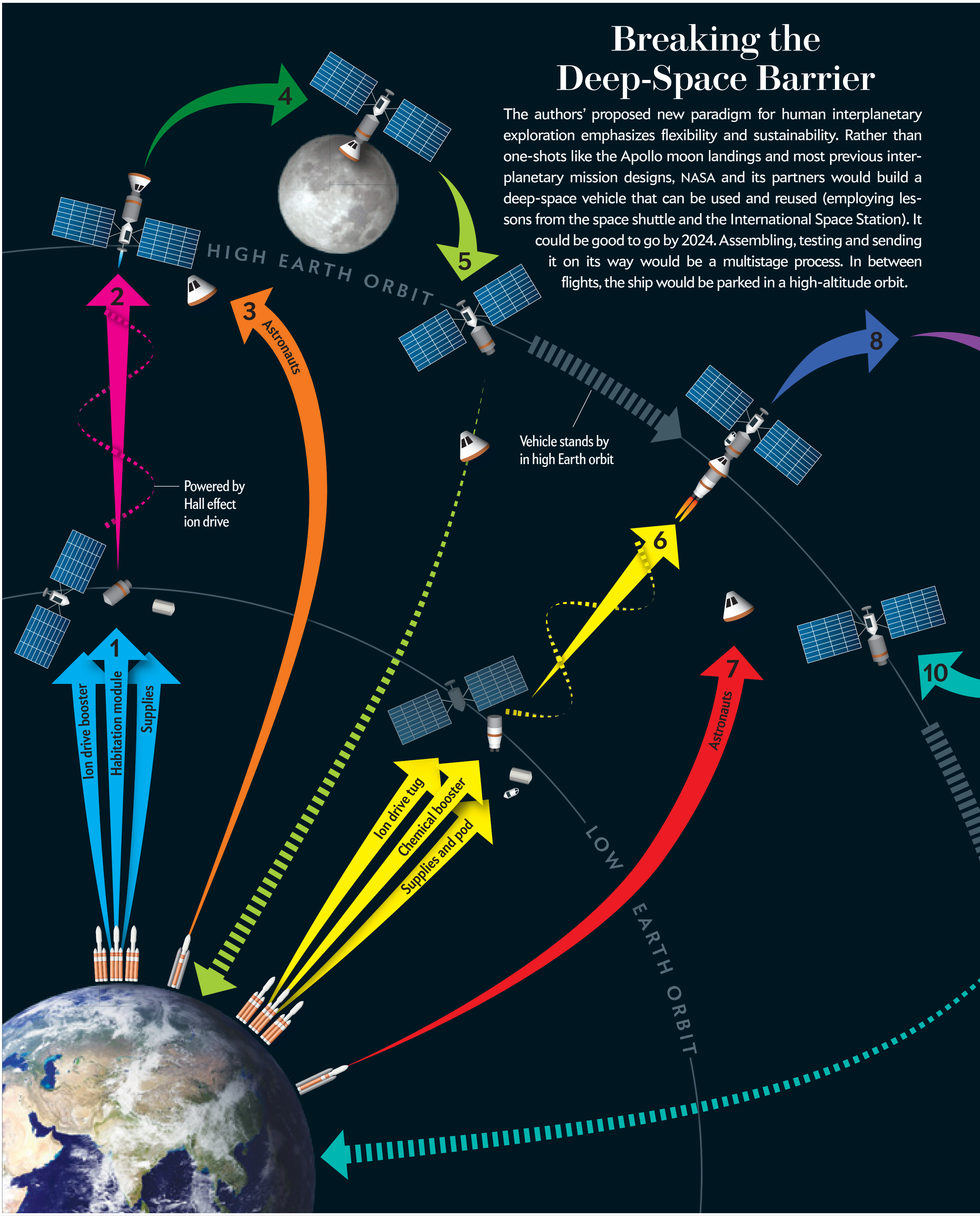
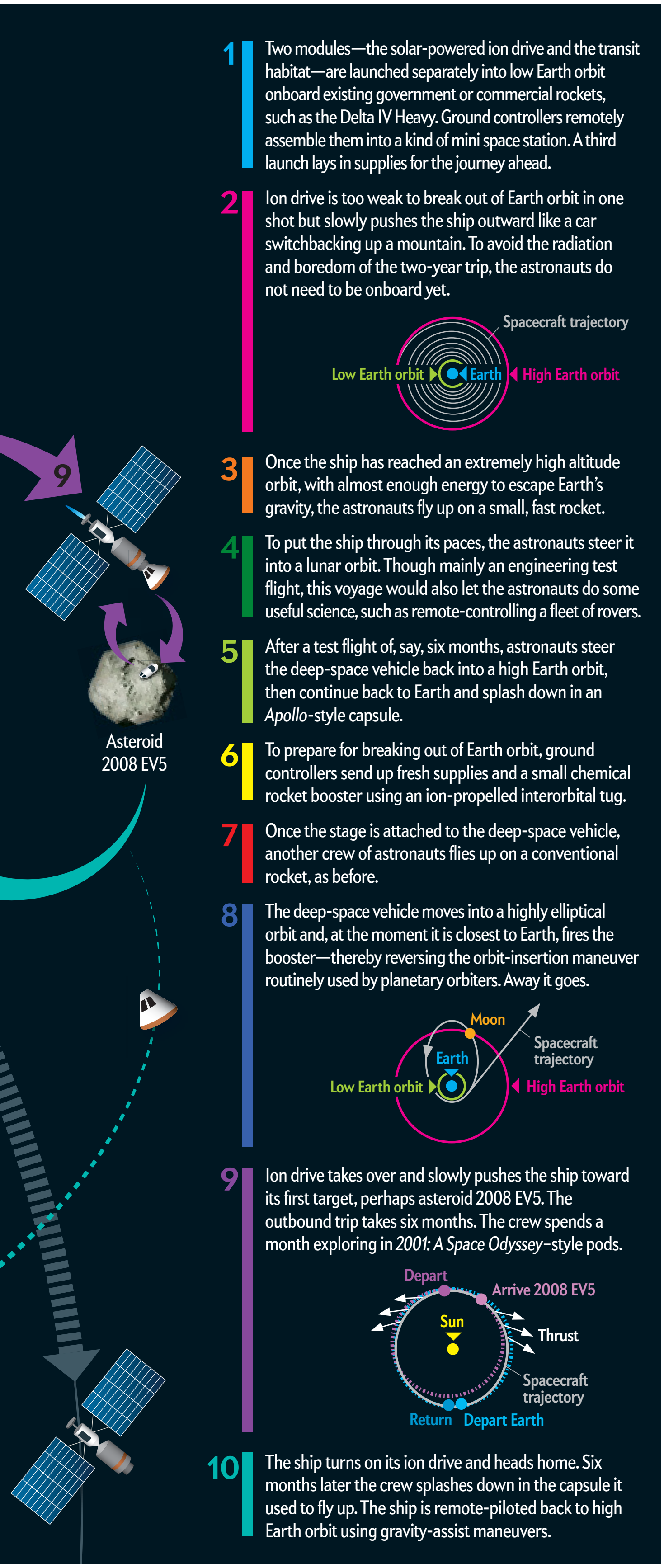


Illustration by Pitch Interactive



NASA (Earth and moon)

of touching down on Mars, traveling around and lifting off again.

Engineers have already come up with various tactics to maximize the flexibility and minimize the cost of a Mars surface mission. The most compelling begin by preplacing habitats and exploration systems on the surface so that the astronauts have a base ready for them when they arrive. This equipment can go by slow (ion) boat. Once there it will produce propellant on Mars itself, either by distilling carbon dioxide from the atmosphere and mixing it with hydrogen brought from Earth to generate methane and oxygen or by electrolyzing water from the permafrost to make liquid hydrogen and oxygen. By sending an empty return rocket that can be fueled in situ, mission planners reduce the launch mass from Earth dramatically [see "The Mars Direct Plan," by Robert Zubrin; Scientific American, March 2000].

The relative motion of Earth and Mars gives the astronauts about one and a half (Earth) years on the surface before the planets come back into alignment, so they will have plenty of time to reconnoiter. At the end of their stay, they board a launch vehicle filled with locally manufactured fuel, blast off to Mars orbit, rendezvous with a deep-space vehicle derived from the asteroid campaign and return to Earth. The vehicle could even be placed on a cycler trajectory that shuttles back and forth between Earth and Mars, using gravity slingshots to provide all the propulsion for free [see "A Bus between the Planets," by James Oberg and Buzz Aldrin; Scientific American, March 2000].

Even with the advance placement of matériel, a Mars lander and return rocket are extremely heavy and will need the largest planned SLS launcher to send them on their way. But the first deep-space missions can be built from smaller parts that are launched on the first SLS or even on existing rockets. The gradualist approach we recommend will maximize the resilience of the program and let NASA concentrate on solving the truly hard problems, such as radiation shielding.

NASA now has the best opportunity in a generation to refocus itself on new types of space vehicles that reach into interplanetary space. The greatest barriers to space exploration are not technical but a matter of figuring out how to do more with less. If NASA plans an incremental sequence of technology development and missions of steadily increasing ambition, human spaceflight can break free of low Earth orbit for the first time in 40 years and enter its most exciting era ever. With flexible planning, NASA can forge a path to wander among the wandering stars. SA

MORE TO EXPLORE

Plymouth Rock: An Early Human Mission to Near Earth Asteroids Using Orion Spacecraft. J. Hopkins et al. Presented at the AIAA Space 2010 Conference & Exposition, August 30–September 2, 2010. http://tinyurl.com/PlymouthRockNEO

Target NEO: Open Global Community NEO Workshop Report. Report of a workshop held at George Washington University, February 22, 2011. Edited by Brent W. Barbee. July 28, 2011. www.targetneo.org

Near-Earth Asteroids Accessible to Human Exploration with High-Power Electric Propulsion. Damon Landau and Nathan Strange. Presented at the AAS/AIAA Astrodynamics Specialist Conference, Girdwood, Alaska, July 21–August 4, 2011. http://tinyurl.com/ElectricPath

300-kW Solar Electric Propulsion System Configuration for Human Exploration of Near-Earth Asteroids. J. R. Brophy et al. Presented at the 47th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, San Diego, July 31–August 3, 2011. http://tinyurl.com/300kWSEP

SCIENTIFIC AMERICAN ONLINE
For a special report on how engineers are reimagining NASA from the inside out, including the little-known story of how Apollo-era engineers planned a Venus flyby, visit ScientificAmerican.com/dec2011/mars

BIOLOGY

DAZZLING MINIATURES

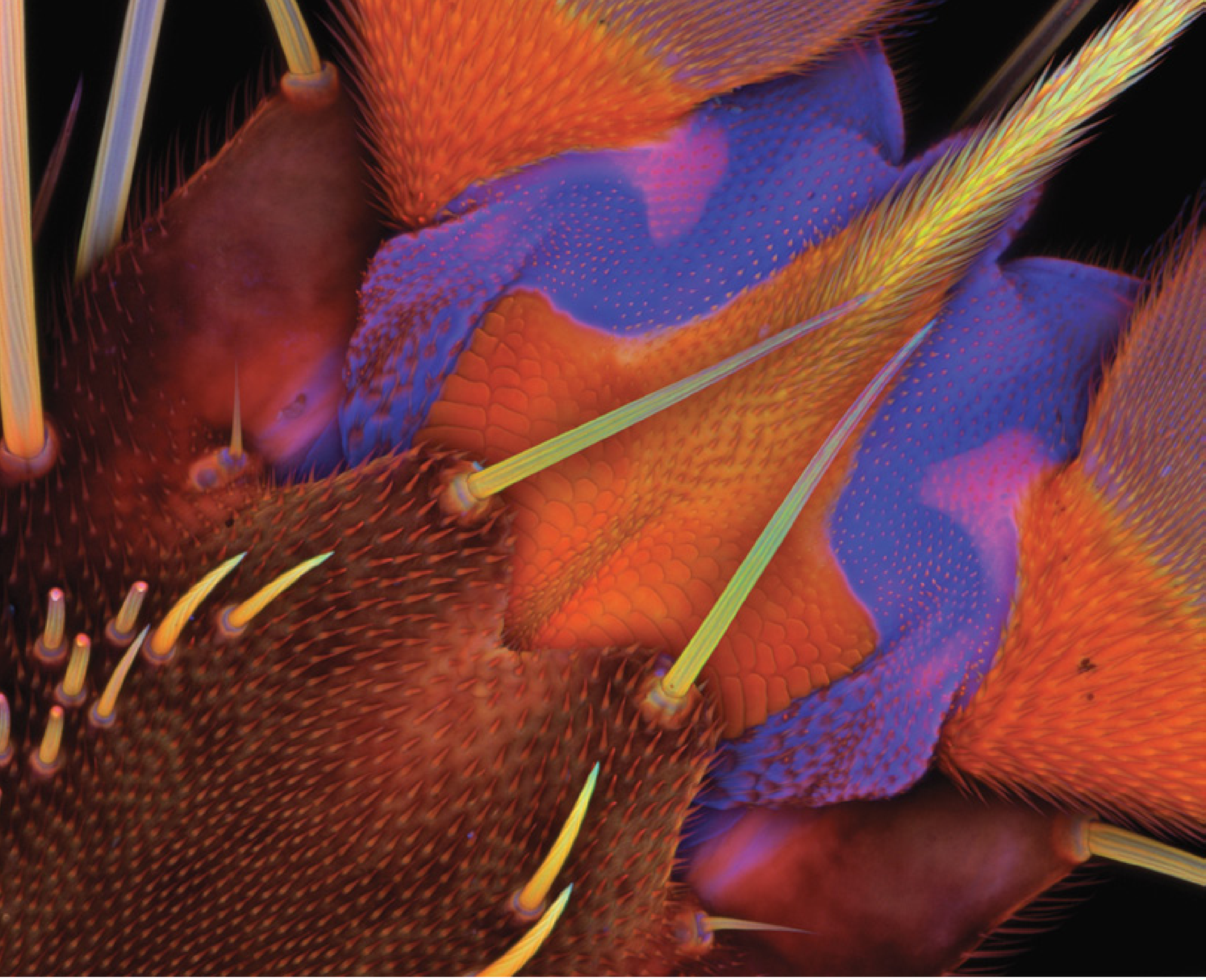
Small worlds writ large under the microscope

By Gary Stix, staff writer

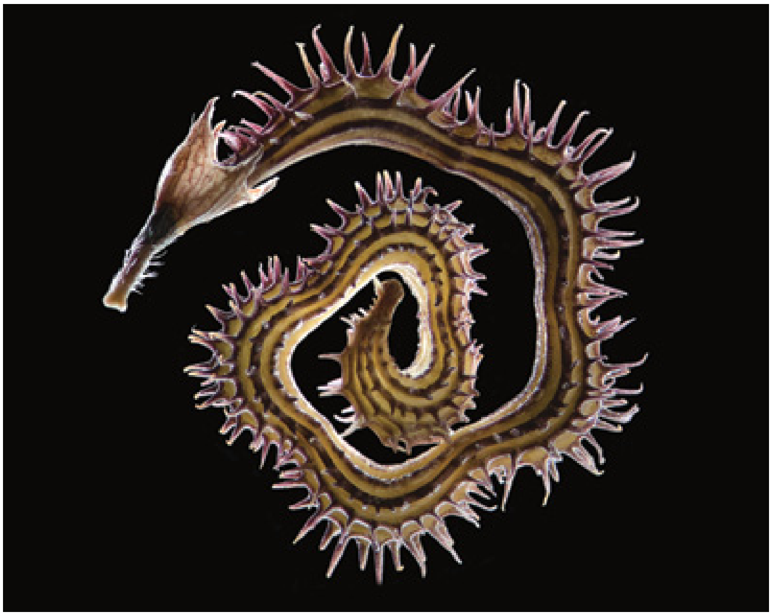
MICROSCOPY REMAINS ONE OF THE FEW AREAS OF SCIENCE IN which enthusiastic amateurs can make others take notice. Nonprofessionals routinely produce stunning images of creatures and objects too tiny for the eye to resolve. This crowdsourcing of microscopic imagery arrived long before the invention of the smartphone and networked communications: the amateur has long made a mark with the microscope—in the early years, by hand drawing images that appeared underneath the lens, and, in more recent times, with the added realism brought by the photograph.

This noble tradition continues in our pages, as we offer a selection of photographs from the Olympus BioScapes International Digital Imaging Competition—a magnet for hobbyists as well as scientists who wish to show off their picture-taking skills. This year's entries feature the work of a lay microscopist who found his subject while hiking on a mountain in Greece. To produce another entry, a cell biologist took a sophisticated microscope acquired at an auction to snap a shot of a translucent zooplankton skeleton. The photo session had nothing to do with his work but served to memorialize the skeleton's sheer structural beauty. Inspect for yourself the hypervivid color and intricate geometry of these Lilliputian neighbors that we too seldom get a chance to meet.

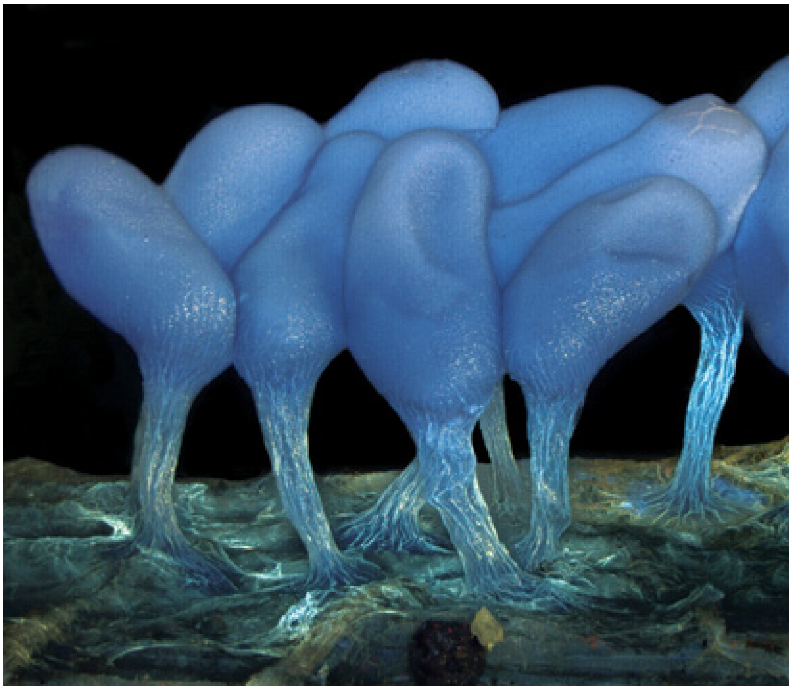
Stinkbug eggs: Amateur photographer Haris S. Antonopoulos found these eggs on top of a mountain near Athens, Greece. He took a series of images of the 1.2-millimeter-diameter eggs and combined them with photo-editing software. The white halos outline the lids through which nymphs emerge.



Hoverfly leg: A section of the leg of a female hoverfly, stretching several hundred microns across, bears two pulvilli, adhesive structures that enable the insect to stick to a surface. The pulvilli, seen here as large, orange appendages at the upper right that form a V shape, are connected to the leg by a spring system (*blue areas*), which consists mainly of the protein resilin. Jan Michels of Kiel University in Germany made the photograph of *Eristalis tenax* as part of a study on the potential of confocal laser scanning microscopy to furnish three-dimensional images of resilin-containing insect body parts.

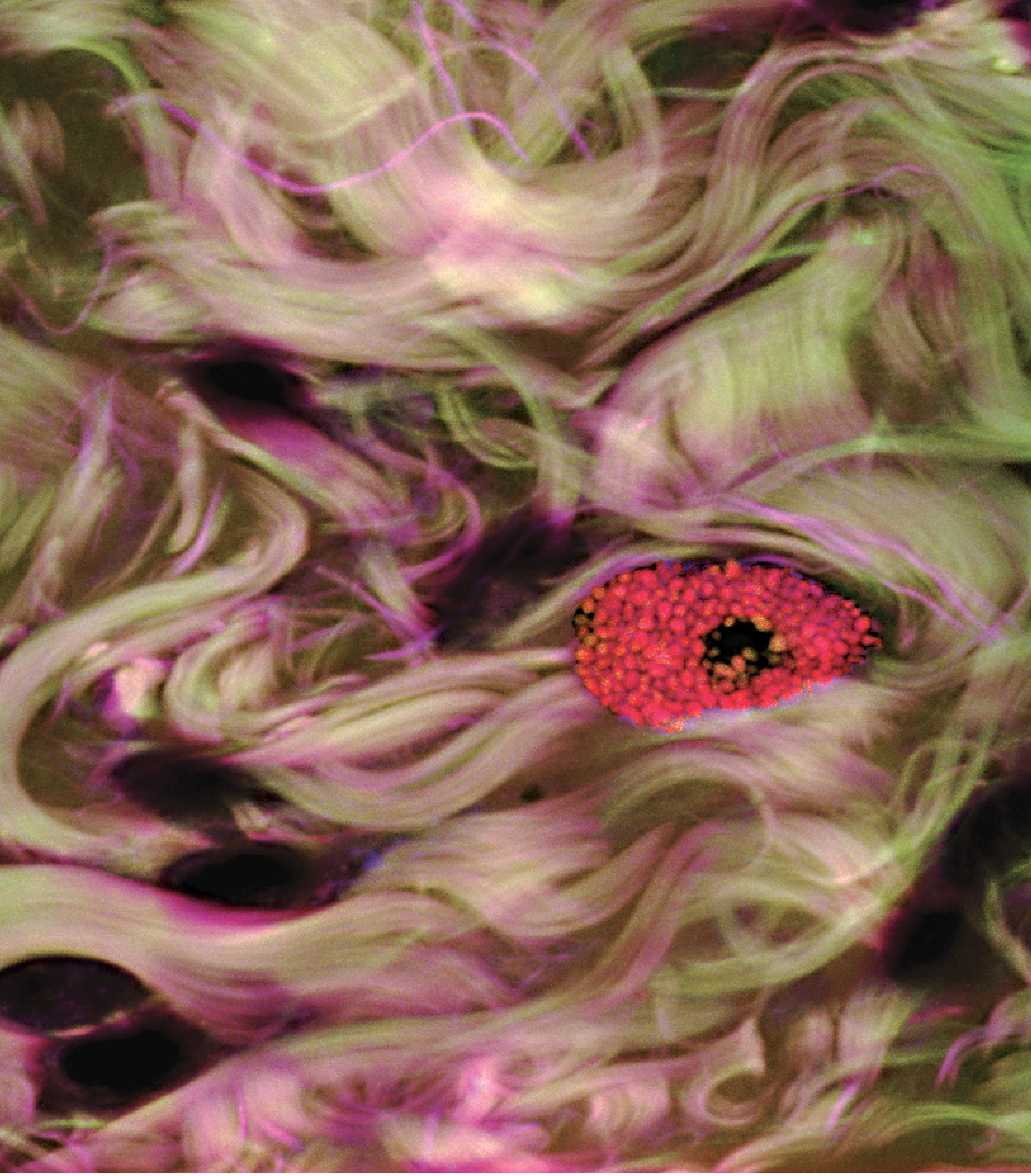


Prickly scorpion's tail: This thin, twisted, five-centimeter-long pod resembles the tail of a scorpion, giving the plant that produced the pod its name. Viktor Sýkora of Charles University's First Faculty of Medicine in Prague does microphotography of plants as a hobby and has published a book on the topic.

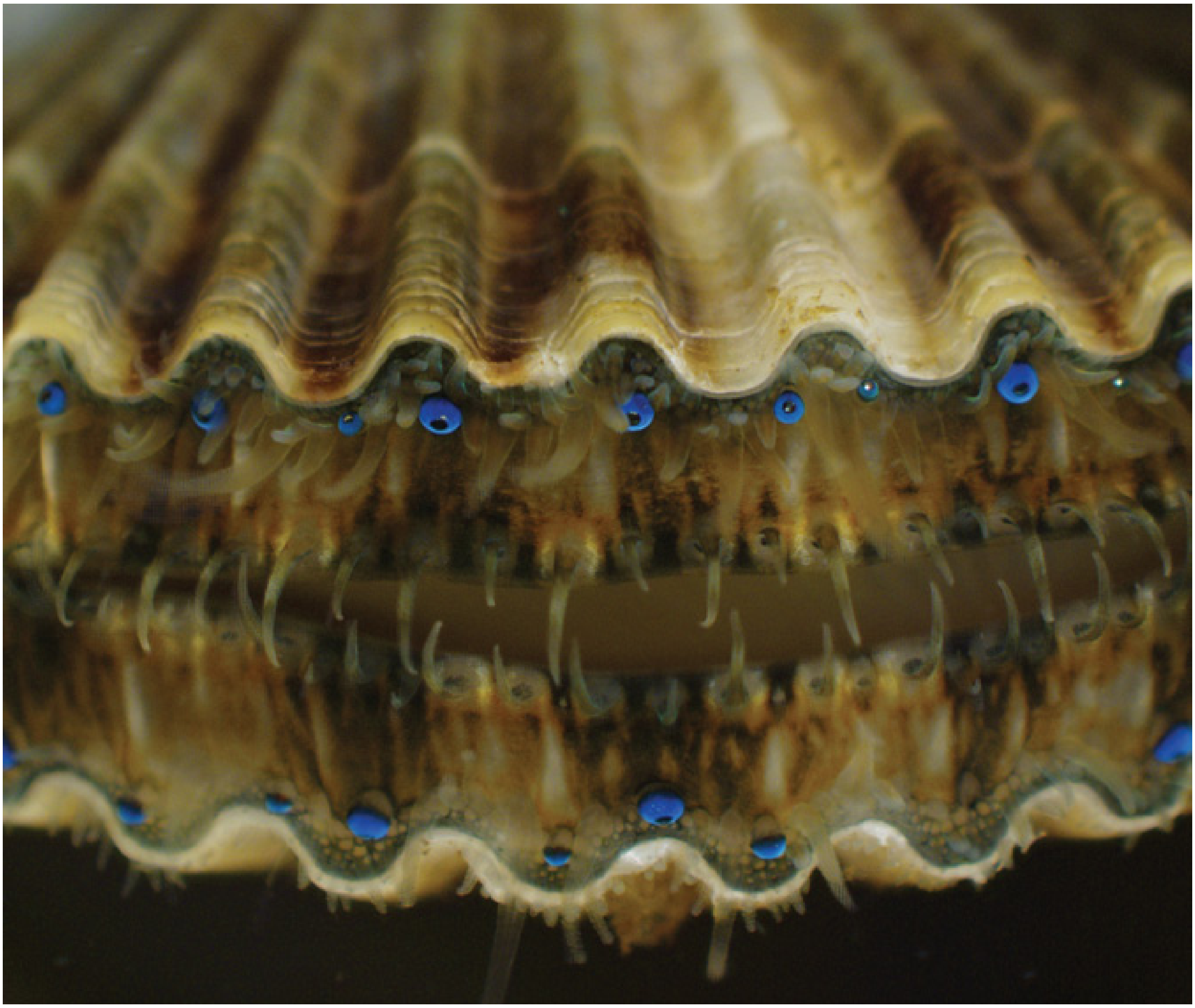


Slime molds: Ultraviolet light causes the mushroomlike fruiting bodies of myxomycetes, or slime molds, to luminesce with a ghostly aura. Dalibor Matýsek, a mineralogist at the Technical University of Ostrava in the Czech Republic who images biological objects as a hobby, used "focus stacking," combining more than 100 scanned images to form a three-dimensional picture of the 4.4-millimeter-tall *Arcyria stipata.*

Rotifer: Two lobes of the corona of the rotifer *Floscularia ringens,* spanning 300 microns, emerge from a protective tube. The cilia at the edge of the corona move in a fast, steady, wavelike motion called a metachronal wave, creating water currents that move food to the rotifer's mouth. The tube consists of reddish-brown circular pellets that the rotifer forms in a cilia-lined socket. A new pellet forms at the center of this first-prize photograph taken by Charles Krebs of Issaquah, Wash. Once the pellet reaches the appropriate size, the rotifer retreats into its tube and, on the way down, quickly but carefully "plants" the new pellet along the top edge of the tube.



Immune cell: A single mast cell has infiltrated the eye surface in response to a perceived invasion by a foreign substance. Mast cells, which contain vesicles of histamine (*red specks*), are among the immune system's first responders, attracting other immune cells to the site of an infection. Here the release of histamine is helping to separate collagen fibers through which the mast cell is migrating. Donald W. Pottle of the Schepens Eye Research Institute in Boston took this confocal microscope image.



Bay scallop: Kathryn R. Markey has a thing about scallop eyes. So she set about recruiting a spat bay scallop from the Luther H. Blount Shellfish Hatchery at Roger Williams University in Bristol, R.I., to show the rest of the world their "majestic eyes"—the blueberrylike circles at the borders of the shell. This exemplar of *Argopecten irradians* went under a stereomicroscope in the university's Aquatic Diagnostic Laboratory, where Markey works, to have its portrait taken.

Radiolarian skeleton: Radiolaria, single-celled, amoebalike creatures that inhabit all the world's oceans, sport radially arranged protrusions called axopodia that here resemble buttons. The axopodia help the critters to float and ingest food. To produce the picture of this 120-micron-long radiolarian skeleton, Christopher B. Jackson of Ikelos in Switzerland took 15 light-microscope images, captured each one at a different focal plane and then combined the set to achieve a sharp image.

MORE TO EXPLORE

For more information about the Olympus BioScapes competition, visit www.olympusbioscapes.com

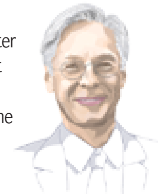
SCIENTIFIC AMERICAN ONLINE
See related videos and more images at ScientificAmerican/dec2011/bioscapes

CLIMATE CHANGE

AFTER THE DELUGE

A spate of floods, droughts and heat waves is prompting city and state leaders to take bold steps to protect their people and property

By John A. Carey



John A. Carey is a freelance writer and former senior correspondent for *BusinessWeek,* where he covered science, technology, medicine and the environment.

FOR A CENTURY WORKERS FLOCKED TO DUBUQUE, IOWA. AS THEY raised new generations of laborers, they built houses, shops and streets that eventually covered over the Bee Branch Creek. The water gurgled through underground pipes out of sight and largely out of memory.

Until the rains came. On May 16, 1999, 5.6 inches of rain fell in 24 hours. The creek pipes and storm sewers overflowed, blowing out manhole covers and turning streets into chest-deep raging rivers. Hundreds of homes and businesses were flooded.

Mayor Roy Buol vividly recalls the neighborhood meeting held a few weeks later. "Everyone was upset," he says. By 2001 the town had devised a master plan to solve the flooding: turn the submerged creek back into an open stream with graded banks capable of handling floodwaters. Of course, that would require tearing down scores of homes. "The plan was not well received," says Deron Muehring, a civil engineer for the city. Planning stalled.

Then, in June 2002, more than six inches of rain fell over two days, sending storm water back into the same homes and buildings that had just been laboriously renovated. That helped to break the political logjam and united city leaders on a $21-million plan to remake the neighborhood, which called for razing homes and adding a verdant park with a stream running through it, along with two water retention basins. Their decision did not hinge on language about climate change or the need to save the planet for future generations. Residents were fed up, and local leaders worried that the neighborhood would irreversibly decline. The city began buying up 74 properties, and groundbreaking took place after yet another drenching in 2010. Engineers have now restored about 2,000 feet of the Bee Branch Creek. When the project is finished in 2013, the city should even be able to withstand repeats of a 10-inch-plus deluge this past July, which caused several million dollars in damage.

Dubuque's actions are a microcosm of a larger tale unfolding across the U.S. Federal policies to combat climate change are stalled, and some members of Congress accuse scientists of making the whole thing up. But cities, towns, water authorities, transportation agencies and other local entities are not interested in debating whether or not climate change is real: they are acting now. Like Dubuque, they are already facing unprecedented floods, droughts, heat waves, rising seas, and the death and destruction these events can impose. "We've got to get serious about adapting," says Iowa State Senator Rob Hogg.

Indeed, about 16 U.S. states have climate adaptation plans or are developing them, according to the Georgetown Climate Center in Washington, D.C., which works with states. [Disclosure: the author's wife, Vicki Arroyo, is executive director of the center.] Although no one has tallied exact numbers, hundreds of communities and agencies are reacting to increasingly severe weather. Those that are not "are going about business as usual with blinders on," says city planner Mikaela Engert, who helped to develop plans for Keene, N.H.

COURAGEOUS INDIVIDUALS

THE EMERGING TAPESTRY of adaptation efforts is being held together by several common threads. The first is that nothing focuses attention more than flooded homes or dried reservoirs in one's community. Even in Dubuque, in conservative Iowa, the argument that climate change is a hoax faded as floods kept coming. "How many of these 500-year events happening every few years do you have to have before you realize something is changing?" Mayor Buol asks. "Whether man is contributing or not, the climate is changing at a faster pace than any time in history."

The second thread is that "all adaptation is local," as Michael Simpson, chair of environmental studies at Antioch University, observes. The San Francisco Bay Area's response to rising seas, which threaten airports, seaports and coastal communities, must obviously be different from Chicago's plan to build "green" roofs, plant trees and install "cool" pavement to tamp down its heat waves. National and regional efforts certainly can play important roles. But adapting to local problems depends on "courageous individuals"

GETTY IMAGES

Impasse: Flooding like this by the Delaware River is forcing towns to plan for severe weather.

who will step up to the challenge, says climate adaptation consultant and Stanford University fellow Susanne Moser.

Those individuals have their work cut out for them because of the final thread: adaptation is difficult. “It’s not a priority for enough people,” Senator Hogg says. The planning process itself is challenging because it must bring together many parties. Even when effective steps can be taken, plans often run into budgetary, political or regulatory barriers. Adaptation gets even harder when the threats are uncertain. Although diversifying water supplies in the face of predicted droughts, as Denver Water is doing, seems clear, it is less clear how to adapt to, say, widespread crop failures such as those in Texas and Oklahoma.

Banking on it: Dubuque, Iowa, opened a buried creek so that it will absorb water during storms instead of flooding town.

COURTESY OF THE CITY OF DUBUQUE

The complexities explain why responses are mixed. On the one hand, “we have made amazing progress in a relatively short period,” says Steve Adams, managing director of the Climate Leadership Initiative in Eugene, Ore. A few examples: the Southern Nevada Water Authority is digging a $700-million water-intake system deeper under Lake Mead so that water will still flow to the Las Vegas Valley when the lake’s water levels drop below the two current intakes, which is likely to happen soon. Toronto has built a new network of storm-water basins and drains in response to a series of recent intense deluges. Maryland is building higher docks and is targeting land for acquisition that can act as buffers against sea-level rise and storm surges.

Vermont, reeling from unprecedented damage from Hurricane Irene, plans to rebuild stronger and better. “Before, we were thoughtfully changing our codes and standards to make our infrastructure more resilient to changing weather from global climate change,” says Gina Campoli, environmental policy manager at the Vermont Agency of Transportation. “Now we are just doing it. We can’t be putting things back the same way if they will just blow out again. We’ve upped the ante here.”

On the other hand, these impressive-sounding developments barely scratch the surface of what is needed. Only a tiny percentage of the nation’s communities are tackling adaptation, Moser notes. Looking at the overall situation, “we are really in bad shape,” argues economist Robert Repetto, author of *America’s Climate Problem*. “We’ve only experienced a portion of the change that we’ve already committed ourselves to because of past greenhouse gas emissions—and emissions are still rising. I don’t think we can adapt.”

MORE RAIN, MORE DROUGHT

MORE ACTION seems warranted because science is painting an increasingly certain picture of a climate being altered by human actions. For instance, climate models predict a rise in average nighttime temperatures, and measurements now unequivocally show that is happening. The phenomenon may be causing a drop in corn yields because plants respire (give off carbon dioxide) more during warmer nights, burning fuel they could otherwise use to plump up their kernels.

The models predict that as the earth’s temperature rises, heat and drought will increase in bands across the American Southwest and the Middle East and that heat waves will become more common at higher latitudes, in places ranging from the upper Midwest to Russia. That is happening, too.

Finally, the models predict more deluges such as the ones that struck Vermont and New York this past summer. For each one degree Celsius rise in temperature, the atmosphere can hold 7 percent more moisture. That means 2 to 3 percent more rain in general but 6 to 7 percent more extreme rainfall events.

Without a big cut in greenhouse gas emissions, “these events will become more common,” says Michael Wehner, a staff scientist at Lawrence Berkeley National Laboratory. “I don’t think anyone disagrees with that.” Work by Peter Stott, head of climate monitoring and attribution at the U.K. Met Office, shows that the odds of a heat wave like the one that struck Europe in 2003 have jumped fourfold compared with preindustrial days.

Even though it is impossible to say that any extreme weather event was directly caused by climate change, that “doesn’t matter, because this is what climate change looks like, and we have to prepare,” says David Behar, climate program director for the San Francisco Public Utilities Commission. A project Simpson worked on used New Hampshire rain-gauge data to show that 10 of the state’s 15 biggest floods since 1934 have occurred in the past 15 years—and that the torrential amounts of rain in what used to be 200-year storms now occur in 25-year storms. Yet most town engineers in New England still design culverts, drains and bridges based on rainfall data from the 1920s to 1950s. “A lot of the infrastructure going in right now is undersized,” Simpson says.

FIRST STEPS

THE HIGHLY POLITICIZED TERM “climate change” does not even need to be invoked to convince communities to revise their practices. Cities and towns that have experienced the worst disasters tend to be on the forefront of adaptation, where local leaders can rally community support to overcome the barriers. A good example is Keene. In October 2005, three days after Simpson presented a report to the city council identifying culverts and roads vulnerable to a major storm, the region was hit by 11 inches of rain.

IN BRIEF

Frustrated by political gridlock in Washington, D.C., over climate change policy, cities and states are changing infrastructure on their own to counteract severe weather that is killing more people and destroying more property.

Dubuque, Iowa, has exhumed a buried creek to reduce storm flooding. Southern Nevada is digging new intake pipes under Lake Mead to offset drought. Keene, N.H., is replacing roads with permeable pavement that allows heavy rain to seep through instead of rising.

Adaptation is best planned by municipalities because solutions must be tailored to local problems, but courageous leaders are often needed to rally support.

The water destroyed those culverts and roads, as well as homes and bridges, shut down the water treatment plant and caused several deaths. The disaster prodded the city, with a little outside help, to develop one of the nation's first and most far-reaching adaptation plans, led by planning director Rhett Lamb, and to find funding for improvements. Sidewalks along one of the city's main roads—Washington Street—have just been replaced with porous concrete, and side roads have been lined with grassy borders instead of curbs, so that in both cases rainwater can spread out and seep slowly into the surrounding ground instead of rising on the road, causing floods.

In Charles City, Iowa, the tipping point was a devastating 2008 flood in which the Cedar River crested nearly three feet higher than its previous record. When people see their homes full of water, "they think about how the number of big rains we get has really changed," says city administrator Tom Brownlow. "It's up to us in leadership to say, 'This is a long-term issue that we need to address.'" The city has. It has torn up 16 blocks of streets and installed permeable pavement atop a thick bed of rock and gravel. The system allows water to pass through into the ground below instead of running off the surface, triggering flooding. In addition, the area under the pavement hosts microorganisms that eat oil and other contaminants before the water sinks through and ultimately reaches the river. The city has also transformed the waterfront with amenities such as a world-class white-water kayaking course. Now "we could get a 100-year rain and not have any standing water in the streets," Brownlow says.

Iowa corn farmers have also responded to the state's increased rains. They have spent tens of thousands of dollars to install more drainage tiles to keep fields from getting too soggy, which can delay planting and stunt crop growth. Ironically, they are also planting up to three times as many seeds per acre, taking advantage of increased spring soil moisture to grow more crops in the same fields. Even though the farmers largely deny that humankind is changing the climate, "they are already adapting and making money at it," says Gene Takle, professor of meteorology and global climate change at Iowa State University.

Floods are an immediate threat of climate change. Yet certain communities are adapting to longer-term ramifications. The San Francisco Bay Area, for instance, plans to spend $20 million to $40 million retrofitting 16 sewer outfalls in the bay to prevent rising seas and storm surges from pushing water back up the outfalls and into sewage treatment plants.

One persistent individual has instilled a long-term view in Hayward, Calif., on the eastern shore of San Francisco Bay. When Bill Quirk, a former NASA climate modeler and nuclear arms expert, won a seat on the city council in 2004, he repeatedly tried to get the city to pay attention to the threat of sea-level rise. No luck. "I was new and didn't know how to get things done," he says.

Then, on New Year's Eve 2005–2006, storm waves at high tide crashed over the city's protective levees, causing heavy damage. At Quirk's behest, the Hayward Area Shoreline Planning Agency scraped up $30,000 to study solutions. In centuries past, sediment washing down creeks and streams built up wetlands along the bay, creating buffers against storm waves. But once the streams were channeled into culverts and pipes, the sediment began flowing out into the bay instead, where it fills in marinas and shipping channels. The agency hopes to start pilot projects that would allow some water and sediment to once again wash back out into the wetlands to help sustain them.

The case for adaptation is harder to make when people are not facing overtopped levees or flooded basements, especially when budgetary and political winds oppose action. In Iowa, Senator Hogg has been pushing a wetlands restoration plan that would slow runoff into rivers, reducing the flooding in cities downstream. But not only has his proposal failed to pass the state legislature, the state's existing programs are being cut. "There are times that feel like I am beating my head against the wall," Senator Hogg says, "but we've got to keep plugging."

FINDING RESILIENCE

NASCENT EFFORTS could use greater federal help. More may be coming. In 2009 President Barack Obama signed an executive order that requires government agencies to develop their own climate adaptation plans—due in mid-2012. Among those taking the task seriously is the Department of Defense, which worries about many installations along vulnerable coasts. The Department of Transportation aims to identify roads, bridges and other infrastructure that could be affected. And wildlife agencies are struggling with ways to keep species, ecosystems and wildlife refuges healthy in the face of shifting climatic zones.

Another push for action could come from the private sector. Reinsurance giant Swiss Re has been working with McKinsey & Company and environmental groups on the economics of climate adaptation. Case studies show that it is far cheaper for a locality to spend some money now to become more resilient than to pay for damages from weather disasters later—an approach that obviously benefits insurers as well. The oil industry has already upped standards for drilling-rig strength to combat more intense hurricanes. Similarly, Joyce Coffee, a vice president at Edelman, who had previously helped develop Chicago's adaptation plan, is trying to convince companies that adaptation could create huge opportunities. A shopping mall owner that chips in for a community's storm-water system upgrades, for instance, earns local goodwill, reduces the property's risk of damage from flooding and boosts the chances that people will still be able to shop when bad weather strikes.

Adapting to climate change is certainly paying off for Dubuque. Unemployment is low, and the renovation is expected to lift property values and create jobs. The city has been named one the top five most resilient cities in the nation, one of the 10 smartest cities on the planet and one of the world's most livable communities. "Cities that get in early on sustainability will have economic advantages, and we are seeing that," Mayor Buol says. SA

MORE TO EXPLORE

Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy. White House Council on Environmental Quality, October 5, 2010. **www.whitehouse.gov**

Our Extreme Future: Predicting and Coping with the Effects of a Changing Climate. John Carey in *Scientific American.* Published online June 30, 2011. **www.scientificamerican.com/article.cfm?id=extreme-future-predicting-coping-with-the-effects-of-a-changing-climate**

The Georgetown Climate Center's Adaptation Clearinghouse (information on state and local adaptation plans): **www.georgetownclimate.org/adaptation/clearinghouse**

SCIENTIFIC AMERICAN ONLINE
For an in-depth report on extreme weather and climate change, see **ScientificAmerican.com/dec2011/extreme-weather**

NEUROSCIENCE

HIDDEN SWITCHES IN THE MIND

Experience may contribute to mental illness in a surprising way: by causing "epigenetic" changes—ones that turn genes on or off without altering the genes themselves

By Eric J. Nestler

Photograph by Plamen Petkov

Eric J. Nestler is Nash Family Professor of Neuroscience and director of the Friedman Brain Institute at the Mount Sinai Medical Center in New York City. His laboratory focuses on uncovering the molecular mechanisms of drug addiction and depression.

MATT IS A HISTORY TEACHER. HIS TWIN BROTHER, GREG, IS A DRUG ADDICT. (Their names have been changed to protect their anonymity.) Growing up in the Boston area, both boys did well in high school: they were strong students in the classroom and decent athletes on the field, and they got along with their peers. Like many young people, the brothers snuck the occasional beer or cigarette and experimented with marijuana. Then, in college, they tried cocaine. For Greg, the experience derailed his life.

At first, he was able to function normally—attending classes and maintaining connections with friends. But soon the drug became all-important. Greg dropped out of school and took on a series of menial jobs in retail and fast-food joints. He rarely held a position for more than a month or two, generally getting fired for missing too much work or for arguing with customers and coworkers. His behavior became increasingly erratic—sometimes violent—and he was arrested repeatedly for stealing to support his habit. Multiple efforts at treatment failed, and by the time the courts sent Greg, then 33 years old, to a psychiatric hospital for evaluation, he was destitute and homeless: disowned by his family and a prisoner of his addiction.

What made Greg so susceptible to the siren song of cocaine—to the point that the drug essentially destroyed his life? And how did his identical twin, who shares the exact same genes, escape a similar fate? How can exposure to a drug set up some individuals for a lifelong addiction, while others can move past their youthful indiscretions and go on to lead productive lives?

These questions are not new, but neuroscientists are beginning to take a fresh approach to finding the answers, borrowing from discoveries first made in other fields. Over the past 10 years biologists studying embryonic development and cancer have uncovered an extensive array of molecular mechanisms that allow the environment to alter how genes behave without changing the information they contain. Instead of mutating genes, these "epigenetic" modifications mark them in ways that can alter how active they are—in some cases for a lifetime.

Now my laboratory and others in the field are finding signs that epigenetic changes caused by drug use or chronic stress can change the way the brain responds to experience: priming an individual to react with resilience or to succumb to addiction, depression or a range of other psychiatric disorders. Although we are still at the earliest stages of understanding this powerful molecular interplay between genes and the environment, we are hopeful that what we learn may lead to improved treatments for these devastating conditions—and may even offer new insights into how mental illness can pass from generation to generation.

BEYOND GENES

OUR EFFORTS to untangle the epigenetic influences on mental illness are helping to fill in blanks left by decades of earlier research into the genetic roots of addiction, depression, autism, schizophrenia and other psychiatric disorders. Like most common medical conditions, these neurological afflictions are highly heritable: roughly half the risk for addiction or depression is genetic—which is greater than the genetic risk for high blood pressure or most cancers. But genes are not everything. As we saw with Greg and Matt, even having identical genes is no guarantee that two individuals will contract the same illness. Instead psychiatric disorders are precipitated in genetically susceptible individuals by environmental inputs—exposure to drugs or stress, say—and can even be influenced by random molecular events that occur during development. No two people will have exactly the same experiences or developmental history.

So the question becomes: By what mechanisms can such inputs lead to mental illness? At one level, the answer is obvious: nature and nurture come together in the nerve cells in the brain. These cells process everything we experience—whether it is watching a movie, getting a hug, snorting cocaine or thinking about what is for dinner—and then share information with

IN BRIEF

New findings suggest that experiences can contribute to mental illness by adding or removing "epigenetic" marks on chromosomes. These tags are particular chemicals that can influence gene activity without changing the information encoded in the genes.

Studies in mice demonstrate a role for long-lasting epigenetic modifications in such disorders as addiction and depression.

Epigenetic changes can also affect maternal behaviors in ways that reproduce the same behaviors in their offspring, even though the changes are not passed down through the germ line.

Researchers hope the new findings will lead to better treatments, although the path to those treatments is not yet obvious.

one another by releasing and recognizing chemicals called neurotransmitters. Neurotransmitters can activate or inhibit individual nerve cells and switch a range of responsive genes on or off. Which genes a particular neurotransmitter affects will help to determine how a nerve cell will respond to an experience and ultimately shapes the way an individual behaves.

Many of these effects last only briefly. For example, exposure to cocaine will activate the reward center in the brain, leading to transient euphoria. That feeling soon fades, and the system resets itself. Still mysterious is how drugs, stress or other experiences can engender longer-term effects, causing an individual to succumb to depression or addiction. That, many neuroscientists are starting to think, is where epigenetics comes in.

MAKING MARKS

TO UNDERSTAND why epigenetics has attracted our attention, it helps to know a little something about how gene activity is regulated. A gene, in simplified terms, is a stretch of DNA that typically specifies the makeup of a protein; proteins carry out most processes in cells and thus control cell behavior. This DNA is not tossed haphazardly into the cell's nucleus. Rather it is wrapped around clusters of proteins called histones—like thread on a spool—and then further bundled into the structures we call chromosomes. The combination of protein and DNA in chromosomes is known as chromatin.

This packaging of DNA does more than keep the nucleus tidy. It also helps to regulate the behavior of the resident genes. Tighter packing tends to keep genes in an inactive state, preventing access by the machinery that turns genes on. In a nerve cell, for example, genes that encode liver enzymes are tucked away in densely packaged chromosomal regions. When a gene is needed, however, the section of DNA on which it resides unfurls somewhat, making the gene accessible to cellular machinery that transcribes the DNA into a strand of RNA. In most cases, that RNA will then serve as a template for producing the encoded protein. Stimulating a neuron, for example, might prompt that cell to boost the transcription of genes coding for certain neurotransmitters, leading to increased synthesis of those messaging molecules.

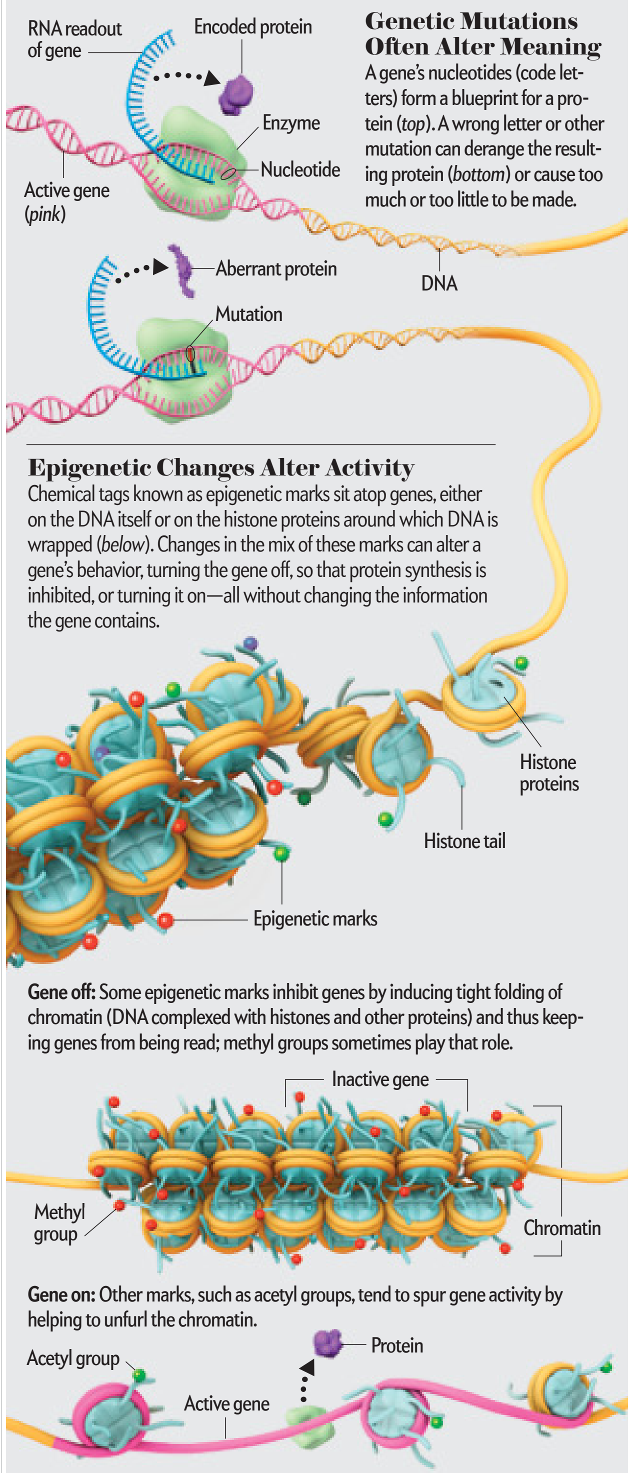
Whether a segment of chromatin is relaxed (primed for activation) or condensed (shut down either permanently or temporarily) is influenced by epigenetic marks: chemical tags that are attached to the resident histones or to the DNA itself. These tags can take various forms and together create a kind of code that indicates how tightly packed the chromatin should be and whether the underlying genes should be transcribed [*see box at right*]. An individual gene may be more—or less—active, depending on how its chromatin is marked.

Epigenetic modifications are made by a variety of enzymes, some of which add the chemical tags and some of which remove them. C. David Allis of the Rockefeller University, a leader in the field, has dubbed these enzymes the "writers" and "erasers" of the epigenetic code. For example, an enzyme known as a histone acetyltransferase, which attaches an acetyl group to a histone protein, is a writer, and a histone deacetylase, which removes this mark, is an eraser. The marks then attract other proteins that act as "readers." Readers bind to specific epigenetic tags and can loosen or condense the surrounding chromatin by recruiting other regulatory proteins that stimulate or repress

BASICS

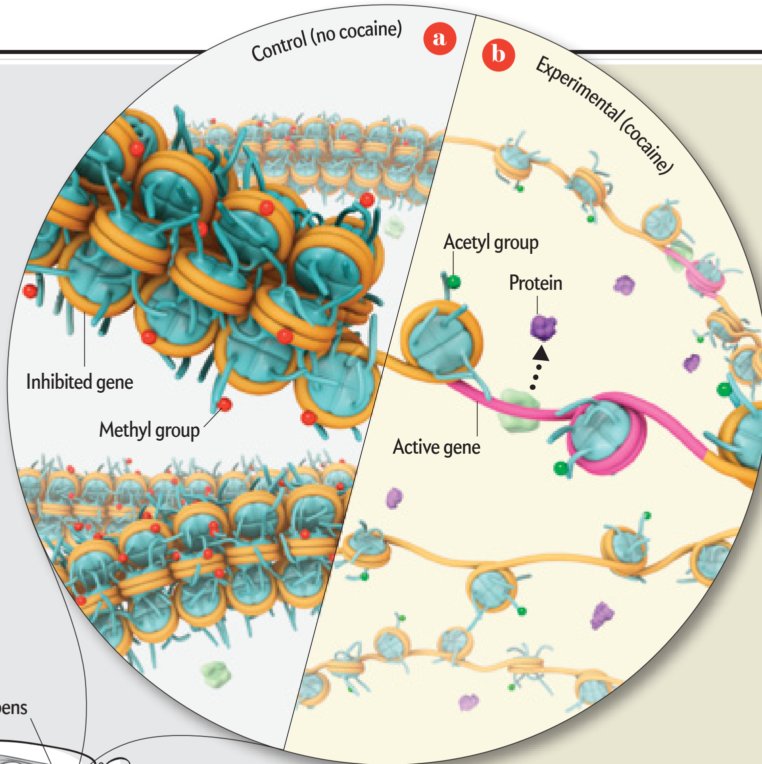
Genetics vs. Epigenetics

Many new insights into mental illness have come from studying epigenetic modifications of genes, which differ from genetic mutations (*below*). Both kinds of alterations can disturb the functioning of the brain and other tissues.



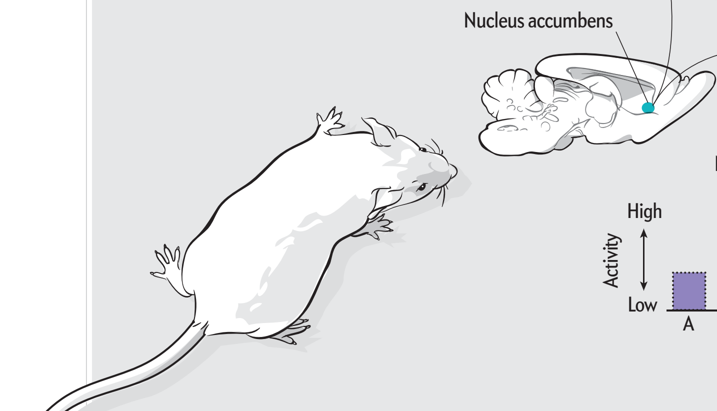
Epigenetics of Addiction

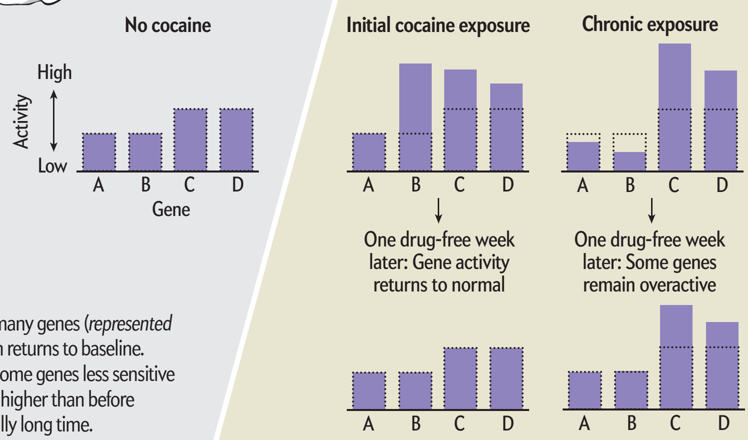
Studies of mice have shown that chronic cocaine exposure shifts the balance of epigenetic marks on genes in the brain's reward center. This shift renders the animals more sensitive to the drug's effects and more prone to becoming addicted.



What Changes Exactly?

Even a single dose of cocaine can alter the epigenetic landscape of genes in the nucleus accumbens, a part of the reward center. In the absence of drugs (a), methyl marks predominate, keeping the affected chromatin tightly wound and its genes quiet. Cocaine causes acetyl groups to predominate and chromatin to loosen (b). Then many genes encoding proteins involved in the pleasurable response to the drug become active.





Lasting Effects

The initial exposure to cocaine transiently elevates the activity of many genes (*represented schematically by changes in B, C and D, near right*), but activity soon returns to baseline. Chronic exposure, however, has more complex effects: it renders some genes less sensitive to the drug (*B, far right*), while boosting the activity of others even higher than before (*C and D*). Some of those genes remain overactive for an abnormally long time.

transcription of the resident genes. Histones that are highly acetylated, for instance, attract readers that tend to open up the chromatin and other proteins that promote gene activation. Histones carrying an abundance of methyl groups, in contrast, attract readers that can either suppress or stimulate transcription, depending on the exact location of the methyl marks.

The environment can influence gene activity by regulating the behavior of epigenetic writers and erasers—and thus the tagging, and restructuring, of chromatin. Sometimes the tags persist for just a short time, say, to allow a nerve cell to respond rapidly to intense stimulation by producing a sustained wave of neurotransmitter release. Often the tags stay put for months or years—or even for the life of the organism: strengthening or weakening the neural connections involved in laying down memories, for example.

The addition and removal of acetyl and methyl groups—and other marks—can thus help the brain to respond and adapt to environmental challenges and experience. My lab and others are now finding in animal studies, however, that these beneficial epigenetic processes can go awry in conditions such as addiction and depression, where alteration of the normal array of modifications may serve to activate cravings, induce feelings of defeat or otherwise predispose an animal to a lifetime of maladaptive behavior. Examination of human brain tissue, retrieved postmortem, suggests that the same may be true in people.

PRIMED FOR ADDICTION

THE FINDINGS related to addiction build on past insights into how drugs of abuse usurp the brain's natural reward center. Many studies, for instance, have identified sweeping changes in the activation of genes in response to cocaine, opiates or other addictive substances. Some of these changes in gene "expression" were shown to persist even after months of abstinence, although researchers have been hard-pressed to explain the mechanism underlying the persistence. Given the long-lasting effects that epigenetic changes can have, about 10 years ago my lab set out to examine whether cocaine could alter the activity of genes in the brain's reward center by changing their epigenetic tagging. Cocaine is a powerful drug that is as addictive in animals as it is in people. Hence, its long-term influences can be readily studied in a lab setting.

A single dose of cocaine induces robust and widespread changes in gene expression, as measured by concentrations of messenger RNA—a direct readout of gene activation. One hour after mice receive their first injection of cocaine, nearly 100 genes get newly switched on. Even more interesting is what happens when animals are chronically exposed to the drug. A handful of the genes turned on by acute exposure to cocaine fall silent if it is given every day. These genes become "desensitized" to the drug.

A much larger number of genes, however, do just the opposite: although they become transiently active in response to the initial exposure to cocaine, chronic exposure to the drug boosts their activity levels even higher—in some cases for weeks after an animal's last injection. What is more, these genes remain highly sensitive to cocaine even after the animal has had no exposure to the drug for some time. Chronic use of cocaine thus primes these genes for future activation—in essence, allowing them to "remember" the rewarding effects of the drug. This priming also sets up the animal for relapse, paving the way to addiction. The heightened sensitivity, it turns out, stems from epigenetic modifications of the genes.

Using powerful techniques for cataloguing the epigenetic marks across the entire mouse genome, we have been able to demonstrate that chronic cocaine administration selectively reconfigures the collection of acetyl and methyl tags on hundreds of genes within the brain's reward center. Collectively, these changes tend to loosen the chromatin structure, rendering these genes more prone to activation by subsequent exposure to cocaine. Again, many of these changes are transient—lasting only a few hours after the animal receives the drug. Some last much longer, however: we have recorded changes that persist for at least a month, and we are beginning to look at even longer periods.

We are also starting to get a handle on the mechanisms that underlie these persistent changes. In our lab, we find that chronic cocaine administration dampens the activity of certain erasers that remove acetyl groups, as well as of particular writers that add inhibitory methyl groups. Chromatin that is more highly acetylated—or less methylated—remains in a more open, relaxed state, making its resident genes more amenable to activation. Chronic cocaine exposure also manipulates the activity of other writers and erasers in the brain's reward center, leaving in its wake an array of epigenetic marks that favor gene activation. In support of this observation, we find that when we artificially tweak the activities of these writers and erasers to mimic the effects of chronic drug use, without actually administering the abused drug, we cause animals to be more sensitive to the pleasurable effects of cocaine—one of the hallmarks of addiction.

The changes in writer and eraser activity following chronic cocaine use are also long-lasting, which may account for the long-term changes in the activities of the marked genes—and the way the animal will respond to a range of future experiences. Because the brain's reward center reacts to such a wide variety of stimuli—including food and sex—manipulating the activity of neurons in this center can fundamentally alter the way an animal behaves.

MARKED FOR DEPRESSION

NEURAL ADAPTATIONS that affect long-term behavior also underlie one of the most chronic, debilitating and common psychiatric conditions: depression. Like addiction, aspects of this disorder can be readily studied in animals. In my laboratory, we work with mice that have been subjected to chronic social defeat. Mild-mannered male mice are paired off with more aggressive animals. After 10 days of being bullied, the docile mice display many of the signs of human depression: they no longer enjoy pleasurable activities (sex, eating sweets), and they become more anxious and withdrawn and less adventurous; they can even overeat to the point of becoming obese. Some of these changes last for months and can be reversed by chronic administration of the same antidepressants used to treat depression in humans.

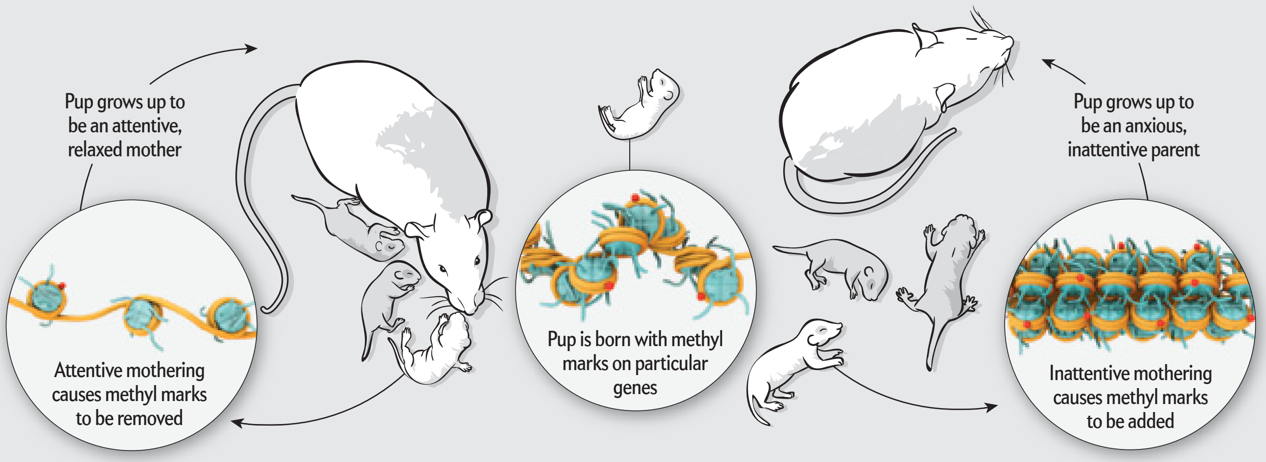
Looking more closely at the mice's DNA, we saw changes in epigenetic modification across some 2,000 genes in the brain's reward center. For 1,200 of these genes, we measured an increase in a particular epigenetic mark—a form of histone methylation that represses gene activity. So it seems that depression may shut down genes important to activating the part of the brain that allows an animal to feel good, creating a sort of "molecular scar." Many of these stress-induced changes, we found, could be reversed by treating the mice for one month with imipramine, a widely prescribed antidepressant. Similar epigenetic changes have been detected in human brain samples obtained from individuals who were depressed at their time of death.

Although depression is a common problem in the human population, not all people are equally vulnerable. And we found the same is true for mice. Roughly one third of the males that receive a daily "dose" of social defeat appear to be resistant to depression: despite being subjected to the same relentless stress, they show none of the withdrawal or listlessness displayed by their susceptible peers. This resiliency reaches down to the level of their genes. Many of the stress-induced epigenetic changes we see in susceptible mice do not occur in the resilient mice. Instead these animals show epigenetic modification of an additional set of genes in the reward center that are not similarly modified in the mice that become depressed. The findings suggest that this alternative pattern of modification is protective and that resiliency is more than just an absence of vulnerability; it involves an active epigenetic program that can be called on to combat the effects of chronic stress.

We also found that the protective genes that are epigenetically modified in resilient mice include many of the same ones whose activity is restored to normal in depressed mice treated with imipramine. A subset of these genes are known to boost the activity of the brain's reward center and, hence, to ward off depression. These observations raise the possibility that, in people, antidepressants may work in part by activating some of the same protective epigenetic programs that function in individuals less prone to depression. If so, in addition to searching for

My Mother, Myself

Studies in rats have shown that epigenetics can influence maternal behavior and that this effect can be passed from one generation to the next by acting on the pup's brain alone, without altering germ cells. When pups are born, genes involved in regulating the animals' responses to stress are decorated with inhibitory methyl marks, which enhance sensitivity to stress. If the pups are raised by a relaxed and nurturing mother, many of their methyl groups will melt away, leaving the animals calmer. When these pups mature, they, too, will be easygoing, attentive parents. If the pups, however, are raised by a fearful, passive mother, their genes will gain methyl marks. They grow up to be nervous and neglectful caretakers.



drugs that block the bad effects of chronic stress, we should also be able to identify drugs that boost the brain's natural mechanisms of resilience.

A MOTHER'S LEGACY

THE EFFECTS I have discussed so far have been seen to persist for a month—the longest time period we have examined. But epigenetic modifications can promote behavioral changes that last a lifetime, as has been demonstrated by Michael Meaney of McGill University and his colleagues. Meaney has examined the effects of maternal care on epigenetic modification—and on the subsequent behavior of the offspring.

The researchers observed that some rat mothers display high levels of nurturing behavior, licking and grooming their pups. Others are less diligent. The offspring of more active mothers are less anxious and produce less stress hormone when disturbed than pups cared for by more passive mothers. What is more, females raised by nurturing mothers become nurturing mothers themselves.

Meaney's group went on to show that the effects of maternal behavior are mediated, at least in part, through epigenetic mechanisms. Pups raised by passive mothers show more DNA methylation than aggressively groomed pups in the regulatory sequences of a gene encoding the glucocorticoid receptor—a protein, present in most cells in the body, that mediates an animal's response to the stress hormone cortisol. This excessive methylation—detected in the hippocampus, a brain region involved in learning and memory—causes nerve cells to make less of the receptor. Because activation of the glucocorticoid receptor in the hippocampus actually signals the body to slow production of cortisol, the epigenetic reduction in receptor number exacerbated the stress response in the animals, making them more anxious and fearful—traits that persisted throughout their lifetime. The effects at the glucocorticoid receptor may be just part of the story. Frances Champagne of Columbia University and her colleagues have found similar epigenetic differences at the gene encoding the estrogen receptor in pups raised by active and passive mothers. It is likely, then, that epigenetic marking of many other genes will turn out to be involved in programming responses to, and thus inheritance of, something as complex as maternal behavior.

In this situation, it seems, epigenetic changes produced in a gene in one generation can, in effect, be handed down to the next generation, even though the changes are not passed through the germ line. A mother's behavior changes the epigenetic regulation of genes in a pup's brain, and then the pup displays the same behavior, which alters the epigenetic markings and behavior in its pup, and so on.

EPIGENETIC CURE

A KEY CHALLENGE in the coming decades will be exploiting what we are learning about epigenetic modifications and behavior to develop improved methods for treating various psychiatric disorders. Our lab and others, for example, have found that drugs that keep histones coated with acetyl groups—by inhibiting the enzymes that erase those marks—have potent antidepressant effects. Furthermore, although passive mothering is associated with changes in DNA methylation, Meaney has found that the same drugs can promote nurturing behavior (because enhanced acetylation can counter the repressive effects of too much methylation).

Although these results are promising, the inhibitors currently on the market are not likely to be useful for combating mental illness. The acetyl erasers—histone deacetylases—regulate epigenetic markings in cells throughout the brain and all over the body, so drugs that disable them indiscriminately have serious side effects and can be toxic. One alternative would be to generate medicines able to selectively inhibit the forms of histone deacetylases that are enriched in areas of the brain most affected in specific psychiatric conditions—the reward center, for example. Another option would be to identify novel proteins involved in epigenetic modification in the brain. In the end, though, the most fruitful approach might be to determine which genes are the subjects of epigenetic modification in depression or addiction: the genes for specific neurotransmitter receptors or signaling proteins, say, that are involved in neural activation. We can then focus our efforts on designing drugs that target the activity of those particular genes—or the protein products of the genes—directly.

PASSING IT ON

ONE INTRIGUING QUESTION that remains to be settled is: To what degree are the epigenetic changes that accompany neuropsychiatric conditions heritable? In Meaney's experiments, rats "inherit" certain behavior patterns—and the accompanying epigenetic profiles—from their mothers. But those changes, which are directly influenced by behavior, occur in the brain. They are not conveyed by marks on genes in the germ cells that form a new embryo. A more provocative question is: Can such experiences cause epigenetic changes in sperm and egg cells, which can then be passed directly to an individual's progeny?

It is certainly not farfetched to think that chronic stress or a drug of abuse could alter the activity of genes in sperm or eggs; after all, stress hormones and drugs are not confined to the brain but flood the entire body, including the testes and ovaries. What is hard to understand, however, is how such a change in sex cells could be maintained across generations. Acquired epigenetic modifications are erased during the type of cell division that gives rise to sperm and eggs. Also, how would the alterations, if present in an embryo, wind up influencing the activity of genes in only select parts of the brain or in the endocrine organs of an adult?

Nevertheless, intriguing work hints that some epigenetic modifications may be heritable. Several groups have found that chronically stressed rodents give birth to offspring that are particularly sensitive to stress. For example, Isabelle Mansuy of the University of Zurich and her colleagues subjected mouse pups to maternal separation during their first two weeks of life and found that, in adulthood, the male offspring exhibit signs of depression. When these males are bred with normal female mice, the resulting offspring also show similar depressionlike behaviors as adults, even though they were not subjected to stress during their upbringing. This transmission of vulnerability to stress correlates with altered levels of DNA methylation of several specific genes in both sperm and brain.

We performed a similar study in our lab. Using our model of social defeat, we subjected male mice to chronic stress. We then waited one month, let these males mate and discovered that their offspring showed a profound increase in their susceptibility to depression. Then we took the experiment one step further. If the epigenetic modifications that make mice susceptible to depression were truly heritable, then the changes should reach the animals' sex cells. So we took sperm from our bullied males and used it to fertilize eggs from a normal female. The offspring of this artificial union, we discovered, were almost completely normal: they showed only slight indications of the withdrawn behavior and anxiety evinced by their fathers.

This experiment is not definitive, because epigenetic marks might somehow be stripped from sperm during the in vitro fertilization process. The results, however, suggest that the females that had physically mated with intimidated males treated their pups differently than females that mated with normal males—or that never met the fathers of their pups. Consequently, the offspring's depression may have stemmed from an early behavioral experience and not from a direct epigenetic inheritance carried through sperm or eggs.

That is not to say that such transgenerational transmission is impossible. Currently, though, we have no definitive evidence to indicate that it occurs. To address that question, we must develop experimental tools that will enable us to identify the relevant epigenetic modifications in germ cells—and to establish that these modifications are both necessary and sufficient to induce the transmission of traits observed.

Eighteenth-century biologist Jean-Baptiste Lamarck was known for his theory of inheritance of acquired characteristics. According to this idea, traits that organisms pick up over a lifetime—a well-exercised musculature, for example—can be passed on to their offspring. Of course, we now know that an individual's genes play the dominant role in determining physiology and function. At the same time, scientists are increasingly coming to appreciate that exposure to the environment and to different experiences (including random occurrences) throughout development and adulthood can modify the activity of our genes and, hence, the ways these traits manifest themselves. And we know now that epigenetic mechanisms mediate this interplay between nature and nurture. We still have much more work to do to fully understand how, and to what extent, epigenetics influences our behavioral traits and susceptibility to mental illness and whether such vulnerabilities can be passed to future generations. No doubt Lamarck and his critics would have delighted in debating the possibilities. SA

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SCIENTIFIC AMERICAN ONLINE
Listen to an interview with the author and learn more about epigenetics at **ScientificAmerican.com/dec2011/epigenetics**

Mark W. Moffett is a research associate at the Smithsonian National Museum of Natural History, where he studies ant behavior. Moffett has traveled throughout the tropical regions of the Americas, Asia and Africa to document ant societies and discover new species for his book *Adventures among Ants* (University of California Press, 2011).

ANIMAL BEHAVIOR

Ants & the Art of War

Battles among ants can be startlingly similar to human military operations *By Mark W. Moffett*

THE RAGING COMBATANTS FORM A BLUR ON ALL SIDES. THE SCALE OF THE violence is almost incomprehensible, the battle stretching beyond my field of view. Tens of thousands sweep ahead with a suicidal single-mindedness. Utterly devoted to duty, the fighters never retreat from a confrontation—even in the face of certain death. The engagements are brief and brutal. Suddenly, three foot soldiers grab an enemy and hold it in place until one of the bigger warriors advances and cleaves the captive's body, leaving it smashed and oozing.

Marauder ants from one colony attack a member of a rival marauder colony, slowly tearing it limb from limb.

Illustration by John Dawson

I back off with my camera, gasping in the humid air of the Malaysian rain forest, and remind myself that the rivals are ants, not humans. I have spent months documenting such deaths through a field camera that I use as a microscope, yet I still find it easy to forget that I am watching tiny insects—in this case, a species known as *Pheidologeton diversus,* the marauder ant.

Scientists have long known that certain kinds of ants (and termites) form tight-knit societies with members numbering in the millions and that these insects engage in complex behaviors. Such practices include traffic management, public health efforts, crop domestication and, perhaps most intriguingly, warfare: the concentrated engagement of group against group in which both sides risk wholesale destruction. Indeed, in these respects and others, we modern humans more closely resemble ants than our closest living relatives, the apes, which live in far smaller societies. Only recently, however, have researchers begun to appreciate just how closely the war strategies of ants mirror our own. It turns out that for ants, as for humans, warfare involves an astonishing array of tactical choices about methods of attack and strategic decisions about when or where to wage war.

1

SHOCK AND AWE

REMARKABLY, these similarities in warfare exist despite sharp differences between ants and humans in both biology and societal structure. Ant colonies consist mostly of sterile females that function as workers or soldiers, occasionally a few short-lived males that serve as drones, and one or more fertile queens. Members operate without a power hierarchy or permanent leader. Although queens are the center of colony life because they reproduce, they do not lead troops or organize labor. Rather colonies are decentralized, with workers that individually know little making combat decisions that nonetheless prove effective at the group level without oversight—a process called swarm intelligence. But although ants and humans have divergent lifestyles, they fight their foes for many of the same economic reasons, including access to dwelling spaces, territory, food and even labor—certain ant species kidnap competitors to serve as slaves.

The tactics ants use in war depend on what is at stake. Some ants succeed in battle by being on the constant offensive, calling to mind Chinese military general Sun Tzu's assertion in his sixth-century B.C. book *The Art of War* that "rapidity is the essence of war." Among army ants, species of which inhabit warm regions around the world, and a few other groups, such as Asia's marauder ant, hundreds or even millions of individuals proceed blindly in a tight phalanx, attacking prey and enemies as they come across them. In Ghana I witnessed a seething carpet of workers of the army ant species *Dorylus nigricans* searching together across an area 100 feet wide. These African army ants—which, in species such as *D. nigricans* that move in broad swathes, are called driver ants—slice flesh with bladelike jaws and can make short work of victims thousands of times their size. Although vertebrate creatures can usually outrun ants, in Gabon I once saw an antelope, caught in a snare, eaten alive by a colony of driver ants. Both army ants and marauder ants will drive rival ants from food—the sheer number of troops is sufficient to overrun any rivals and control their food supply thereafter. But army ants almost always hunt en masse with a more malicious aim, storming other ant societies to seize the colony's larvae and pupae as food.

The advancing phalanxes of army and marauder ants are reminiscent of the fighting formations that humans have used from ancient Sumerian times to the regimented fronts of the American Civil War. Marching together in this way, without a specific target, as humans sometimes did, makes every raid a gamble: the ants might proceed over barren ground and find nothing. Other ant species send a far smaller number of workers called scouts out from the nest to search separately for food. By fanning out across a larger area while the rest of the colony stays home, they encounter more prey and enemies.

Yet colonies that rely on scouts may kill fewer adversaries in total because a scout must return to its nest to assemble a fighting force—usually by depositing a chemical called a pheromone for the reserve troops to follow. In the time it takes a scout to assemble those troops for battle, the enemy might have regrouped or retreated. In contrast, the workers of the army ants or marauder ants can immediately summon any help they require because a slew of assistants are marching directly behind them. The result is maximal shock and awe.

ALLOCATING THE TROOPS

IT IS NOT JUST the huge number of fighters that makes the army and marauder ants so deadly. My research on marauder ants has shown that troops are deployed in ways that increase efficiency and reduce the cost to a colony. How an individual is deployed depends on the female's size. Marauder ant workers vary in size more than workers of any other ant species. The tiny "minor"

IN BRIEF

Some kinds of ants live in tight-knit colonies containing thousands or millions of individuals that go to war with other colonies over resources such as territory or food.

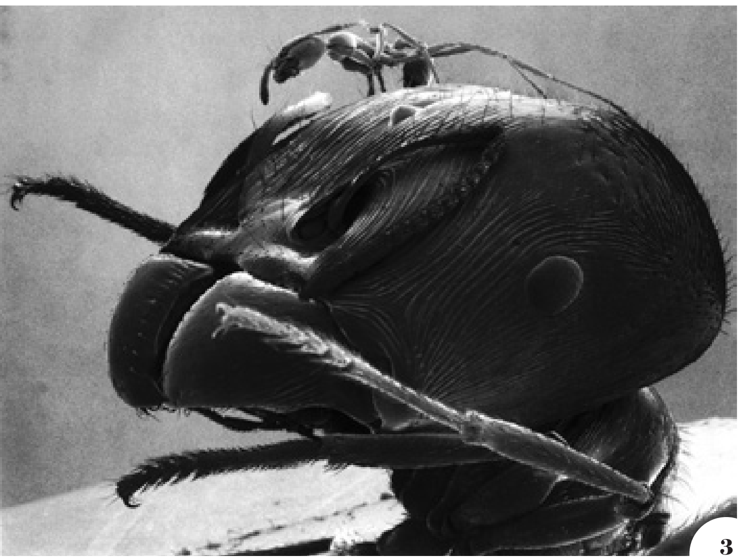
The diverse tactics these insects use in combat can be remarkably similar to human war strategies, varying according to what is at stake.

The ants' capacity for warfare is enhanced by their unbreakable allegiance to their colony.

CONSULTANT: STEFAN COVER *Museum of Comparative Zoology, Harvard University (preceding pages)*

2

On the battlefield: Highly territorial weaver ants spread-eagle a much stronger army ant, eventually tearing it to pieces (*1*). Smaller honeypot ant stands on a pebble to look larger, a tactical deception that scares its bigger foe away (*2*). Minor worker of the marauder species rides on the head of a major worker of the same species; minors catch enemies, whereas majors kill them (*3*). Reddish suicide bomber ant ruptures its own body to spray a toxic yellow glue on its enemy, killing both instantly (*4*).



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MARK W. MOFFETT *Minden Pictures*

workers (the foot soldiers of my opening description) move quickly to the front lines—the danger zone where competing ant colonies or prey are first encountered. A single minor has no more chance against the enemy than would an equally small scout of a lone-hunting species. But their sheer numbers at the front of a raid present a commanding barricade. Although some may die along the way, the minors slow or incapacitate the enemy until the larger workers, known as the medias and the majors, arrive to deliver the deathblow. The medias and the majors are much scarcer than the minors but far more lethal, with some individuals weighing 500 times as much as one minor.

The minors' sacrifices on the front lines assure a low mortality for the medias and the majors, which require far more resources for the colony to raise and maintain. Putting the easily replaced fighters at greatest risk is a time-honored battle technique. Ancient river valley societies did the same thing with conscripted farmers, cheaply obtained and available in droves, who absorbed the worst of the warfare. Meanwhile the elite soldiers, who received the best training and the finest weapons and armor, remained relatively safe within these hordes. And just as human armies may defeat their enemies by attrition, destroying unit by unit rather than attacking a whole force at once—a tactic known to military strategists as "defeat in detail"—so, too, do marauder ants mow down enemies a few at a time as a raid advances instead of engaging the enemy's entire strength.

In addition to killing other enemy species and prey, marauder ants intensely defend the areas around their nests and food from other colonies of their own kind. The medias and majors hang back while each minor grabs an opponent's limb. These confrontations last for hours and are deadlier than the jostles that occur between the marauder and its other competitors. Hundreds of little ants become interlocked over a few square feet as they slowly tear one another asunder.

This insect variant of hand-to-hand combat represents the common mode of killing among ants. Mortality is nearly certain, reflecting the cheapness of labor in a large colony. Ants that are less cavalier about loss of troops employ long-range weapons that allow them to hurt or impede the enemy from afar; for example, stunning their enemy with a Mace-like spray, as *Formica* wood ants from Europe and North America do, or dropping small stones onto enemy heads as *Dorymyrmex bicolor* ants from Arizona do.

Research conducted by Nigel Franks, now at the University of Bristol in England, and his colleagues has demonstrated that the organized violence practiced among army ants and marauders is consistent with Lanchester's square law, one of the equations developed in World War I by engineer Frederick Lanchester to understand potential strategies and tactics of opposing forces. His math showed that when many fights occur simultaneously within an arena, greater numbers trump individual fighting power. Only when dangers become extreme do the larger marauder ants put themselves at risk—for example, workers of all sizes will rush an entomologist foolish enough to dig up their nest, with the majors inflicting the most savage bites.

Still, just as Lanchester's square law does not apply in all situations for warring humans, neither does it describe all the behaviors of warring ants. Slave-making ants offer a fascinating exception. Certain slave makers steal the brood of their target colony to raise as slaves in the slave maker nest. The slave makers' tough armor, or exoskeleton, as it is termed, and daggerlike jaws give them superior fighting abilities. Yet they are greatly outnumbered by the ants in the colonies they raid for slaves. To avoid being massacred, some slave makers release a "propaganda" chemical that throws the raided colony into disarray and keeps its workers from ganging up on them. In so doing, as Franks and his then University of Bath graduate student Lucas Partridge have shown, they are following another Lanchester strategy that at times applies also for humans. This so-called linear law holds that when battles are waged as one-on-one engagements—which is what the propaganda substance allows—victory is assured for the superior fighters even when they are outnumbered. In fact, a colony besieged by slave makers will often allow the invaders to do this plundering without any fighting or killing.

Among ants, a fighter's value to its colony bears on the risks the ant takes: the more expendable it is, the more likely it is to end up in harm's way. The guards lining marauder foraging trails, for instance, are usually elderly or maimed workers that often struggle to stay upright while lunging at intruders. As Deby Cassill of the University of South Florida reported in *Naturwissenschaften* in 2008, only older (months-old) fire ants engage in fights, whereas weeks-old workers run off and days-old individuals feign death by lying motionless when under attack. Viewed from the ant perspective, the human practice of conscripting healthy youngsters might seem senseless. But anthropologists have found some evidence that, at least in a few cultures, successful human warriors tend to have more offspring. A reproductive edge might make combat worth the personal risk for people in their prime—an advantage unattainable by ant workers, which do not reproduce.

TERRITORIAL CONTROL

OTHER HUMANLIKE military strategies emerge from observations of weaver ants. Weaver ants occupy much of the canopy of tropical forests in Africa, Asia and Australia, where colonies may span several trees and contain 500,000 individuals—comparable to the enormous populations of some army ants. Weavers also resemble army ants in being highly aggressive. Yet the two have entirely different modi operandi. Whereas army ants do not defend territories because they stay packed together while roaming in search of other ant species to attack for food, weaver colonies are entrenched at one site, spreading their workers wide within it to keep competitors out of every inch of their turf.

They handily control huge spaces within the trees by defending a few choke points such as the spot at which the tree trunk meets the ground. Leafy "barrack nests" placed strategically in the crowns distribute the troops where they are most needed.

Weaver ant workers are also more independent than army ant workers. Army ant raids function by stripping away the workers' autonomy. Because the army ant troops confine themselves to the close quarters of their advancing pack, they require relatively few communication signals. They respond to enemies and prey in a highly regimented way. Weavers, in contrast, wander more freely and are more versatile in their response to opportunities and threats. The differences in style call to mind the contrasts between the rigidity of Frederick the Great's armies and the flexibility and mobility of Napoleon Bonaparte's troops.

Like army ants, weaver ants take similar tacks in dealing with prey and destroying an enemy: in both cases, a weaver deploys a short-range recruitment pheromone from its sternal gland to summon nearby reinforcements to make the kill. Other weaver ant communiqués are specific to warfare. When a worker returns from a fight with another colony, it jerks its body at passing ants to alert them to the ongoing combat. At the same time, it deposits a different scent along its path, a pheromone released from the rectal gland that its colony mates follow to the battlefield. Moreover, to claim a previously unoccupied space, workers will use yet another signal, defecating in the spot, much as canines mark their territory by urinating on it.

Shut the front door: Door-making ant of the genus *Stenamma* (*middle*) uses a pebble to block an army ant (*left*) from entering its nest.

MARK W. MOFFETT *Minden Pictures*

A MATTER OF SIZE

FOR BOTH ANTS AND HUMANS, the propensity to engage in true warfare is related at least in a rough way to the size of a society.

Small colonies seldom conduct protracted battles except in defense. Like human hunter-gatherers, who are often nomadic and tend to live hand to mouth, the tiniest ant societies, which contain just a few dozen individuals, do not build a fixed infrastructure of trails, food stashes or dwelling places worth dying for. At times of intense conflict between groups, these ants, like their human counterparts, will often choose flight over fight.

Modestly sized societies will likely have more resources to defend but are still small enough to be judicious about jeopardizing their troops. Honeypot ants of the southwestern U.S., which live in medium-size colonies containing a few thousand individuals, provide an example of danger mitigation by these insects. To harvest nearby prey unchallenged, a honeypot colony may stage a preemptive tournament near a neighboring nest to keep the enemy busy rather than risking deadly battles outright. During the tournament the rivals stand high on their six legs and circle one another. This "stilting" behavior mirrors the mostly bloodless, ceremonial displays of strength commonplace in small human clans, as biologists Bert Hölldobler of Arizona State University and E. O. Wilson of Harvard University first suggested. With luck, the colony with the smaller stilting ants—typically from the weaker colony—can retreat without loss of life, but the winning side will wreak havoc on their enemies given the opportunity, devouring the loser's brood and abducting workers called repletes that are swollen with food they regurgitate on request for hungry nest mates. The honeypot victors will drag the repletes back to their nest and keep these living larders as slaves. To avoid this fate, reconnaissance workers survey the tournament to assess whether their side is outnumbered and, if necessary, set in motion a retreat.

Full-bore conflicts appear to be most common for ant species with mature colonies composed of hundreds of thousands of individuals or more. Scientists have tended to consider these large social insect societies inefficient because they produce fewer new queens and males per capita than smaller groups do. I see them instead as being so productive that they have the option to invest not only in reproduction but in a workforce that exceeds the usual labor requirements—much like our bodies invest in fatty tissue we can draw on in hard times. Different researchers have posited that individual ants have less work to do as colonies grow larger and that this leaves more of them inactive at any one time. Colony growth would thereby amplify the expansion of a dedicated army reserve that can take full advantage of Lanchester's square law in its encounters with enemies. Similarly, most anthropologists see human warfare as having emerged only after our societies underwent a population explosion fueled by the invention of agriculture.

SUPERORGANISMS AND SUPERCOLONIES

ULTIMATELY THE CAPACITY for extreme forms of warfare in ants arises from a social unity that parallels the unity of cells in an organism. Cells recognize one another by means of chemical cues on their surface; a healthy immune system attacks any cell with different cues. In most healthy colonies, ants, too, recognize one another by means of chemical cues on their body surface, and they attack or avoid foreigners with a different scent. Ants wear this scent like a national flag tattooed on their bodies. The permanence of the scent means ant warfare can never end with one colony usurping another. Midstream switches in allegiance are impossible for adult ants. With perhaps a few rare exceptions, each worker is a part of its natal society until it dies. (Not that the interests of ant and colony always coincide. Workers of some species can attempt to reproduce—and be thwarted—much as conflicts of interest between genes can occur within an organism.) This identification with their colony is all ants have because they form anonymous societies: beyond distinguishing castes such as soldiers from queens, ant workers do not recognize one another as individuals. Their absolute social commitment is the fundamental feature of living as part of a superorganism, in which the death of a worker is of no more consequence than cutting a finger. The bigger the colony, the less a small cut is felt.

The most breathtaking example of colony allegiance in the ant world is that of the *Linepithema humile* ant. Though native to Argentina, it has spread to many other parts of the world by hitching rides in human cargo. In California the biggest of these "supercolonies" ranges from San Francisco to the Mexican border and may contain a trillion individuals, united throughout by the same "national" identity. Each month millions of Argentine ants die along battlefronts that extend for miles around San Diego, where clashes occur with three other colonies in wars that may have been going on since the species arrived in the state a century ago. The Lanchester square law applies with a vengeance in these battles. Cheap, tiny and constantly being replaced by an inexhaustible supply of reinforcements as they fall, Argentine workers reach densities of a few million in the average suburban yard. By vastly outnumbering whatever native species they encounter, the supercolonies control absolute territories, killing every competitor they contact.

What gives these Argentines their relentless fighting ability? Many ant species, as well as some other creatures, including humans, exhibit a "dear enemy effect," in which, after a period of conflict, death rates sharply decline as the two sides settle on a boundary—often with an unoccupied no-man's-land between them. In the floodplains where Argentine ants originated, however, warring colonies must stop fighting each time the waters rise, forcing them to higher ground. The conflict is never settled; the battle never ends. Thus, their wars continue unabated, decade after decade.

The violent expansions of ant supercolonies bring to mind how human colonial superpowers once eradicated smaller groups, from Native Americans to Australian Aborigines. Luckily, humans do not form superorganisms in the sense I have described: our allegiances can shift over time to let immigrants in, to permit nations to fluidly define themselves. Although warfare might be inescapable among many ants, it is, for us, avoidable. SA

MORE TO EXPLORE

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SCIENTIFIC AMERICAN ONLINE
More ant photos are available at **ScientificAmerican.com/dec2011/ants**

Colleen Fitzpatrick is a forensic genealogist, who has traced hundreds of people around the world for both civilian and military organizations. She is based in Huntington Beach, Calif.

FORENSICS

ARM IN THE ICE

New fingerprint- and DNA-identification techniques solve a mystery from a 60-year-old plane crash

By Colleen Fitzpatrick

ON MARCH 12, 1948, AT 9:14 P.M. PACIFIC STANDARD TIME, NORTHWEST AIRLINES FLIGHT 4422 crashed into Mount Sanford, a peak in the remote Wrangell Mountains in eastern Alaska. All 24 passengers—merchant mariners returning to the U.S. from Shanghai, China—along with six Northwest crew members, probably died on impact. The debris, too difficult to reach, was quickly covered by snow and eventually entombed by ice.

There it remained until 1999, despite many failed efforts to find it. In that year Kevin McGregor and Marc Millican, two former U.S. Air Force pilots who like to solve forgotten aviation mysteries, having determined that the glacier containing the plane was retreating, gained permission from the National Park Service to recover parts of the wreckage if they could find it. After an arduous climb, they discovered scattered debris, along with a desiccated left arm and attached hand in the ice. As McGregor explains, "That changed the entire project. We became compelled to find out to whom the arm and hand belonged."

McGregor and Millican's quest to identify the remains eventually led to an unusual collaboration of DNA experts, fingerprint analysts and forensic genealogists, including myself. Our challenging and ultimately successful effort may benefit many more families than just those of the doomed men onboard the Northwest flight. Some of the laboratory techniques developed during our investigation may one day prove helpful in identifying victims of mass disasters and more than 800 unknown soldiers who died during the Korean War.

INITIAL SETBACKS

THE DISCOVERY of human remains brought Alaska law-enforcement agencies into the picture. A state trooper carefully freed the arm and transported it to the medical examiner's office in Anchorage, some 200 miles away. After taking impressions of the finger pads, the medical examiner embalmed the remains.

Because the arm and hand bore no distinguishing marks, fingerprinting and DNA analysis were the only possibilities for making a conclusive identification. After three years, however, it became clear that standard methods would not solve the mystery. An extensive search for fingerprint records turned up only 22 so-called ten-print cards, leaving no records for eight victims, including the six crew members. Even had there been a full set of reference prints for each victim, however, the dried-out hand was so badly damaged by exposure to the elements that the Alaska medical examiner's office would have been unable to make a positive identification.

Investigators were stymied on the DNA front as well. In 2002 the medical examiner's office sent a tissue sample to a commercial DNA laboratory. Alas, the lab reported that the biological material had "degraded to a point where the DNA strands were too small to get intelligible results."

McGregor and Millican—now joined by Randall Haslett, the son of the flight's purser—decided to search for a research scientist who specialized in making identifications with ancient DNA. Their quest led

Tragedy: It took nine years to identify the arm recovered from the wreckage of Northwest Flight 4422. No one knows what caused the crash. The plane was off course before it slammed into the mountain.

MICHAEL S. QUINTON *Getty Images* (*mountain*); COURTESY OF NORTHWEST AIRLINES HISTORY DEPARTMENT (*airplane*); COURTESY OF KEVIN A. McGREGOR, © 1999 (*man with camera*); COURTESY OF ROY WITTOCK (*arm*); ALASKA STATE TROOPERS/AP PHOTO (*van Zandt*); COURTESY OF MIKE GRIMM, JR. (*fingerprint*)

Illustration by Mario Wagner


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first to Ryan Parr of Genesis Genomics (now Mitomics) and then, in 2006, to Odile Loreille of the Armed Forces DNA Identification Laboratory (AFDIL) in Rockville, Md. Loreille is known for analyzing highly degraded DNA. Rather than looking at the DNA found in the nuclei of cells, however, she studies the DNA in mitochondria, the tiny organelles that cells use to create energy. Because cells have so much more mitochondrial DNA (mtDNA) than nuclear DNA, mtDNA offers a better chance of identifying very degraded remains.

Loreille was interested in the Northwest Airlines project because she thought it might help her solve the mystery that brought her to AFDIL: how to identify the remains of more than 800 unidentified U.S. soldiers from the Korean War. Most of these men are interred in Hawaii in the National Memorial Cemetery of the Pacific, otherwise known as the Punchbowl. The formaldehyde used to embalm the servicemen's remains had substantially damaged their DNA. If Loreille could use the Northwest case to develop new techniques for analyzing embalmed tissue, it would be another step in her efforts to help the armed forces identify the remains of these Korean War veterans.

All in all, Loreille knew, the best chance of success was to obtain DNA from the arm's bone tissue, which is usually better protected from contamination by the environment and from the DNA of anyone who handled the remains. She had recently discovered how to more efficiently separate formaldehyde residue from bone. But even that process was unlikely to generate enough material. During the course of our investigation, however, Loreille developed a demineralization process that completely dissolved the bone matrix, providing just enough mtDNA for analysis.

Of course, DNA extraction was only half of the story. To make an identification, the mtDNA from the decades-old tissue would have to be compared with that of a family reference for each candidate until a match was obtained. Because mtDNA is passed to each child only from the mother, any male or female relative could serve as a reference as long as he or she was linked to the candidate through an exclusively matrilineal line. This requirement often makes it difficult to locate distant relatives who can provide mtDNA, given that a woman's family name typically changes at marriage. That is where I came in. As a forensic genealogist, I have traced hundreds of people worldwide for many reasons, including DNA referencing for the military and in connection with historical projects.

PARALLEL EFFORTS

IN TRYING TO NARROW the possibilities while speeding up the identification process, Loreille turned for help in 2007 to Ted Robinson, an assistant professor of forensic science at George Washington University. Although the earlier fingerprint analysis had not been successful, a second attempt with new techniques might conceivably rule out some of the candidates. Then it would not be necessary to locate living relatives to provide DNA references for all 30 men.

The fingerprint analysis, performed in parallel with the mtDNA identification, quickly presented its own challenges. Fingerprint identification relies on three levels of detail. Level 1 takes into account the general pattern of the skin's friction ridges, which allow an individual to grip objects. This pattern falls into one of three categories—loops, whorls or arches. (There is only one type of ridge pattern per finger.) Level 2 details are known as minutiae, or Galton points, in honor of Sir Francis Galton, whose work laid the foundation in 1892 for the current system of recording and identifying fingerprints. Minutiae include places where the line of an individual ridge splits into two, develops a spur, includes a dot or simply comes to an end. On the finest scale, level 3 describes the characteristics of individual ridges, such as their thickness and their level of convexity or concavity. It also includes the locations of sweat pores. Comparing level 1 details in two sets of fingerprints is sufficient to rule someone out as a match; however, it is not specific enough to use for a positive identification. Level 2 and 3 details must be used for such determinations.

By this point, the epidermal layer of skin was no longer present on the fingers—it had sloughed off since the arm's removal from the ice, and the underlying dermis was almost smooth. Furthermore, only 16 of the original 22 ten-print cards from Northwest Flight 4422 could now be located, so there were no reference prints for 14 of the victims. Nevertheless, Robinson persevered. He attempted to restore the pliability of the skin by bathing it in specially formulated rehydration fluids. Forensic scientists refer to this process as fingerprint rejuvenation. Coincidentally, Robinson had just met Michael Grimm, a retired supervisor from the state of Virginia's Department of Forensic Science, at a conference. Grimm gave Robinson a sample of a new rejuvenation fluid that had been employed in the identification of victims of Hurricane Katrina in 2005 and that could possibly produce results within hours.

The fluid did the trick. Robinson soaked the hand at 122 degrees Fahrenheit (50 degrees Celsius), checking the results hourly as finger-ridge detail slowly emerged on all five fingers. After photographing the results, Robinson took casts of the prints using two types of silicone rubber. When he removed the finger pads and soaked them separately, the fingerprint detail improved even more. After Grimm photographed the finger pad casts and imported the digital images into a photo-enhancing software program, the prints were so clear that even the sweat

Unofficial fingerprint records and a marriage certificate provided the final clues that led to a positive identification.

IN BRIEF

More than 50 years after the 1948 crash of a Northwest Airlines plane killed all onboard, a desiccated arm and hand were retrieved from the scene.

Initial fingerprint examination and DNA analysis of the arm and hand were unable to determine the identity of the remains.

Researchers finally identified the remains after developing new techniques that may one day be used for disaster victims and unknown soldiers.

pores were visible on the 60-year-old hand.

Ironically, the high quality of the photographs created a new problem. As Robinson explains, "A lot of [the mariners' cards] were overinked, smudged and just poorly done. The fingerprints from the hand were now better than the prints from the ten-print cards. Because of the poor quality of the ten-print cards, identification could not be made." Still, Robinson knew that all five fingers of the hand from the crash site had loops, so he was able to rule out 10 victims by discerning that each had at least one finger with an arch or a whorl on his left hand. Grimm eliminated four more based on the finer details in the loops.

IDENTIFICATION AT LAST

IN THE MEANTIME, forensic genealogist Chriss Lyon and I worked to find living relatives who might provide the necessary reference samples for the remaining victims. By September 2007, 13 of the 30 men had been ruled out by mtDNA, nine had been ruled out on the basis of fingerprints alone, and five had been ruled out by both mtDNA and fingerprints. That left three men: purser Robert Haslett and merchant mariners Francis "Frank" Joseph van Zandt and John V. Elkins.

Unfortunately, the fingerprint records for Haslett were illegible, and there were no living matrilineal relatives for him who could provide mitochondrial DNA for comparison. (A mitochondrial DNA sample from Haslett's son, Randall, could prove a relationship only to Randall's mother and her relatives.) But father and son did, of course, share their Y chromosome, so Loreille used advanced laboratory techniques to amplify the amount of DNA from the nuclear material in the arm to create a partial profile of the unknown victim's Y DNA. It did not match Randall's.

Only two candidates remained. John Elkins's relatives declined to give samples of their DNA, and his fingerprint records were too smudged to be of use. Fortunately, our luck was about to change, finally giving our team what we needed to determine whether the arm had belonged to Elkins or van Zandt.

According to vital records, Frank van Zandt was born on October 21, 1911, in Bennington, Vt., the youngest child of Orville van Zandt, Sr., from New York State and Margaret Conway from Ireland. Frank had one sister, named Elizabeth (whose children might have served as mtDNA references), but we found no trace of her or any possible descendants after the 1910 U.S. census. Going back a generation, the search for collateral female-linked Conway lines in the U.S. also ran into trouble. I learned that Margaret Conway immigrated with two sisters (and three brothers) to the U.S. in the 1890s. Unfortunately, one sister never married, and the other sister did not have any surviving female lines.

Perhaps Margaret had left sisters behind in Ireland? I had done 40 years of Irish genealogical research, and so I knew that Irish civil and church records are organized by county. To find Margaret, I had to discover her county of origin. After searching through thousands of records, I got a lucky break from Bill Budde, the archivist at the Bennington Museum. Budde discovered that the 1936 marriage record of Frank's brother, Orville, Jr., recorded his (and therefore Frank's) mother's birthplace as "Limerick." A search of Irish birth registrations revealed that Margaret was born September 14, 1871, to John Conway and Ellen Drumm from County Limerick. There was more good news: Margaret had left three sisters and a brother in Ireland. But finding their descendants more than 100 years later was not going to be easy.

During my painstaking search for Conway-Drumm descendants, I was eventually referred to Maurice Conway, the patriarch of the Conway family of the village of Askeaton. He did not initially recognize any of the names we had of van Zandt's Conway ancestors. Ultimately, however, I learned that Maurice's maternal great-great-grandmother, Elizabeth, was Ellen Drumm's sister—that is to say, he and van Zandt shared a common maternal ancestor. Because Maurice was a matrilineal relative, therefore, a sample of his mitochondrial DNA could be used for the identification.

Loreille compared the mtDNA from the arm against all 19 of the reference samples that were now available for the men onboard Flight 4422. The DNA sequence from the remains matched one reference only, that of van Zandt's maternal cousin, Maurice Conway. For added confirmation, we located van Zandt's brother's son, who agreed to serve as a Y-DNA reference. The partial Y-DNA profile that had ruled out Robert Haslett matched that of van Zandt's nephew at every locus.

Robinson and Grimm had meanwhile discovered that in their search for fingerprint records, they had been asking the wrong question. Instead of requesting "official" fingerprint records, they should have been asking for "any" fingerprint records. They were surprised to learn that the National Maritime Center had extra fingerprint records of many of the merchant mariners that had been taken when they signed on to a new ship. These new records gave us van Zandt's prints for the first time, allowing Robinson and Grimm to match van Zandt's fingerprints to those taken from the 60-year-old hand. Their efforts produced the oldest postmortem fingerprint identification on record.

We now had independent, corroborating results from both DNA and fingerprint analysis identifying the arm in the ice as having belonged to Francis Joseph van Zandt. As for the unknown soldiers of the Korean War, Loreille continues her research to identify their remains. Her work on extracting DNA from embalmed tissue suggests that it may be possible to recover enough mtDNA from the Korean-era remains to identify them. She is now working with newly developed DNA-sequencing technologies that, in the next few years, might make identifications feasible using extremely small amounts of DNA—whether from long-dead soldiers or victims of mass disasters.

Our results also showed the importance of working across disciplines. Whereas DNA experts, fingerprint analysts and forensic genealogists often try to answer the same questions about identity and relationships, we typically confine our efforts to our respective professional domains. Our highly collaborative investigation of Northwest Flight 4422 shows that cross-disciplinary efforts can produce robust results, especially in very difficult cases. SA

MORE TO EXPLORE

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To learn about the Korean War accounting effort: **www.dtic.mil/dpmo/korea**

For more information about forensic genealogy: **www.identifinders.com**

SCIENTIFIC AMERICAN ONLINE
Listen to Kevin McGregor describe the quest to find the wreckage of Northwest Airlines Flight 4422 and view a slide show of photographs at **ScientificAmerican.com/dec2011/plane-wreck**

EDUCATION

Speaking Out on the "Quiet Crisis"

Strengthening science education is the key to securing our energy future, says Rensselaer Polytechnic Institute's president

Interview by Brendan Borrell

IN BRIEF

WHO
SHIRLEY ANN JACKSON

LINE OF WORK
Advocate in chief for building the reputation of a major research university

WHERE
Rensselaer Polytechnic Institute

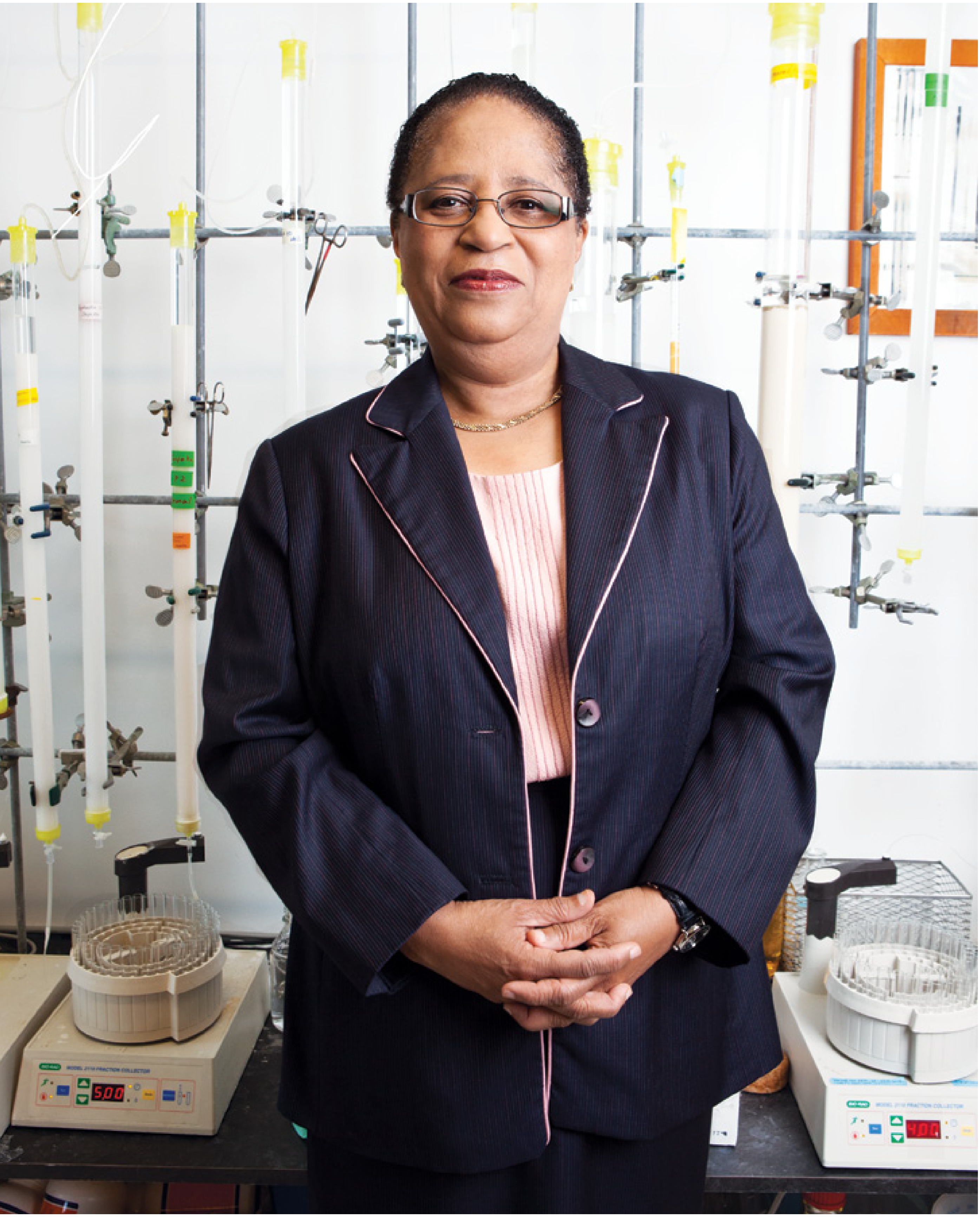
BIG PICTURE
Science literacy will play a vital role in addressing major national challenges such as formulating energy policy.

ON ENERGY AND EDUCATION
"If we don't have the right talent, we're not going to be able to meet our energy needs."

WHEN SHIRLEY ANN JACKSON WAS IN ELEMENTARY SCHOOL IN THE 1950S, SHE would prowl her family's backyard, collecting bumblebees, yellow jackets and wasps. She would bottle them in mayonnaise jars and test which flowers they liked best and which species were the most aggressive. She dutifully recorded her observations in a notebook, discovering, for instance, that she could alter their daily rhythms by putting them under the dark porch in the middle of the day. The most important lesson she took away from these experiments was not about science but compassion. "Don't imprison any living thing for very long," she says in a mellow drawl that belies her reputation as a lightning-fast thinker and influential physicist. "I have never been a fan of dead insect collections."

Jackson came of age during the civil-rights movement. She was valedictorian of her graduating class at Roosevelt High School in Washington, D.C., in 1964 and went on to study particle and high-energy physics. In 1973 she became the first African-American woman to receive a Ph.D.

At AT&T Bell Laboratories (now Bell Labs), Jackson studied materials for the semiconductor industry from 1976 to 1995. She also worked at other research institutions in the early 1970s, including Fermilab in Batavia, Ill., and CERN near Geneva. In 1995 President Bill Clinton appointed her chair of the Nuclear Regulatory Commission. Four years later she took the helm of Rensselaer Polytechnic Institute (RPI) in Troy, N.Y.—making her the first female African-American president of a top-50 research university. Since then, RPI has raised more than $1 bil-



Photograph by Spencer Heyfron

lion in philanthropic donations, set up new departments, such as the Computational Center for Nanotechnology Innovations, and attracted a Nobel laureate and members of the National Academies.

Jackson has strong views about the importance of science education and the underrepresentation of minorities in academia. Her inspiring life story has even been published as a children's book. In a recent interview, Jackson spoke about how a "quiet crisis" in science training is threatening our nation's energy security in the face of challenges such as global warming and the Fukushima nuclear disaster. Excerpts follow.

***Scientific American*: Growing up in Washington, D.C., at a time when there was so much turmoil, how were you able to focus on science?**

JACKSON: My parents believed very strongly in education and in helping each of their children pursue their interests. My father, who was in charge of motor vehicle operations for the U.S. Postal Service, would work with me on science projects, and he actually helped my sister and me design and build go-karts. He had a natural mechanical and mathematical capability even though he was not college-educated. My mother, meanwhile, taught her children to read early.

I also benefited from great teachers. Before desegregation, the teachers that I had were quite good and focused on nurturing talent, but afterward the school system brought in a unique group of African-American teachers. They thought it was a great experiment, so they wanted these special teachers to come in. I tested into an accelerated academic track and had relatively small classes with just seven to 10 students. So that, coupled with having more access to more resources and, frankly, more competition, helped us to grow and think more broadly about career options.

How did you make the leap from bees to physics?

To be honest, I didn't think about physics per se until I was in college. As I went along from grade school to middle and high school, I got progressively more interested in mathematics and how it could help describe physical phenomena. I went off to college with math in mind, but then I took a physics course when I was a freshman at M.I.T. called PANIC, which stands for Physics: A New Introductory Course. I also had an inspiring professor named Tony French [who worked on the Manhattan Project], and I kind of loved quantum mechanics.

Is there a particular discovery you are most proud of?

In the late 1970s engineers wanted to create new semiconductor devices, and at Bell Labs we knew that the quantum physics of two-dimensional structures was going to govern their electrical behaviors. I created mathematical models of these systems, and I guess the work I am best known for is studying polarons on the surface of liquid-helium films. People refer to the polaron as a particle that digs its own grave. It can be an electron or any kind of charged particle that distorts the structure that it is moving through. This creates a feedback system, slowing, for instance, those same electrons, and I found that under certain conditions the conductivity of a material could quickly drop to zero. This phenomenon, later seen in experiments, is what got me elected as a fellow of the American Physical Society.

Your physics education came in handy as chair of the Nuclear Regulatory Commission in the 1990s. Do you think the Fukushima disaster will affect the debate over nuclear power and energy policy?

It is a complex picture. Countries seem to be reexamining their nuclear programs in three ways: some, like Germany, are looking at whether they want to continue down the nuclear power path. Others, such as the U.S., are continuing to extend the license terms of nuclear plants but are having discussions about how to strengthen the safety of existing reactors and how to anticipate and mitigate the effects of natural disasters. Then there are those in developing economies and in ones that have not had nuclear programs that are continuing right on down the line of building new reactors. Iran, for instance, recently connected its reactor to its grid. I think Japan is going to continue its program even though there is some pressure to scale back. There will be a pause and then a continuation of nuclear power in most countries.

Are the challenges for the industry different today than when you were chairing the commission?

The overall performance of nuclear plants has improved over time. The designs of the newer, more evolutionary plants have anticipated certain kinds of accidents. Some of the things we did when I was chair of the NRC, including the promulgation of risk-informed, performance-based regulation, sharpened our focus on where the greatest safety problems are. But we are still faced with the Achilles' heel of nuclear waste disposal at the back end of the fuel cycle.

What do you think the answer is for spent-fuel storage?

There are broader policy issues that society must address. One is whether to bury the fuel in a geologic repository, such as Yucca Mountain [in Nevada], within the matrix of other radionuclides, which some feel deters nuclear proliferation. Alternatively, there could be reprocessing of the spent fuel to extract plutonium and make mixed-oxide fuel. The point is that any discussion of nuclear power should be in the larger context of an overall energy security plan for the country.

What do you mean by "energy security plan"?

We tend to lurch from sector to sector. We talk about nuclear and what we should do with nuclear. We talk about oil and gas and who the bad guys are and who the good guys are. But if we don't develop a comprehensive energy security plan, we're going to be having these discussions until the cows come home.

In the end, energy security is about having adequate supplies of energy at rational prices across a spectrum of uses: transportation, residential and commercial uses.

Is this what you have called "intersecting vulnerabilities"?
It's exactly what I call it. If we do not take account of intersecting vulnerabilities, we tend to lurch one way and then the other. The oil spill in the Gulf of Mexico and the Fukushima disaster tell us there is vulnerability when we are looking at any given energy source. With Fukushima, the plants shut down the way they should have, but they needed water, and that requires the ability to pump water, and that requires electricity that doesn't come from the reactor. The power outages that we have recently had here in the Northeast coming from Hurricane Irene tell us about the vulnerabilities in terms of our infrastructure, certainly for electricity transmission, if not for generation itself. These things tell us that we need a diversity of energy sources.

Do you see renewable energy as a significant part of that equation?
As we look to newer technologies, we also have to think about how we optimize what we have with less environmental impact. We have to think about environmental sustainability and conservation. A watt saved is de facto a watt generated. But we'd also better think about full life-cycle costs. If we want to have compact fluorescent lightbulbs, how are we going to dispose of the mercury in the bulbs in an environmentally sound way? If we are going to have electric cars, what infrastructure do we need to make that happen? There are no easy solutions, and we are addicted to easy solutions. If we commit to looking at the whole energy life cycle, it can help us make choices, particularly if we then play into the markets where there should be transparency of pricing and consistency of regulation.

In the end, what we seem to have lost focus of is this: if we're going to have energy security, we're going to have to innovate. I've never seen any innovation yet that just popped out of the air. It comes from people's ideas. So if we don't have the right talent, we're not going to be able to meet our energy needs.

Is the U.S. losing its edge when it comes to investing in innovation?
Yes, we are underinvesting in people and in R&D in the energy sector and more generally. We can see that people are leaving science and engineering. We have a group of people who are beginning to retire, the number of retirements will continue to grow and we do not have students to replace them. Our performance on international tests and achievement in things like math and science are slipping. We see where other countries are generating more intellectual property or having their work cited frequently. You can pick your metric, but in combination you see a slippage. This is what I call the "quiet crisis."

The biggest evidence in some ways is that other countries are investing more in the very areas that we are backing away from. And they are trying to emulate the model that has made us successful. A huge part of our GDP growth after World War II in America came from scientific discovery and technological innovation. It came out of government investment in infrastructure. Google's entire business would not exist without government-funded R&D. They have armies of smart people writing algorithms, thinking about how to do ever better things in their space. But they are riding on top of an infrastructure—the Internet, GPS and integrated circuits—that was funded by the government.

The private sector also has to play a leadership role because it, too, needs to invest in research. And that is something that has dropped off in recent years quite a bit.

Which brings me to the three-legged stool: government, industry and academia all have a role in providing infrastructural, financial and human capital to produce the innovations we need.

Has the slow rate of growth of underrepresented minorities in science affected our competitiveness?
Regarding the issue of minorities being underrepresented, I see many factors. We have to begin with K–12 education. That affects all of us overall, but it obviously has disproportionately affected minorities. We need better math and science teachers. We need programs at the K–12 level to really get young people engaged early and give them the fundamental grounding and the preparation required. If they do not have that, then they do not have as many options further down the educational pipeline.

For those who become students in science and engineering, we need to support them financially and nurture and mentor them, whether they are women, minorities or majority males. If people see people who are like themselves as faculty or in significant positions in corporations, these things will help.

My message is that if we want innovation, we need the innovators. We have to tap the complete talent pool. Sometimes I think a mistake we make is this: because the problems are so serious, we want to separate out underrepresented minorities and women from the larger issues. They do need special attention, but I think there would be more urgency about it if people understood that women and minorities are key parts of the complete talent pool. We need to educate people for their career, for their life, and not just for their first job. We need to invite, excite and prepare young people. And teachers make a difference.

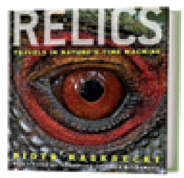
***Brendan Borrell,** based in New York City, frequently writes for* Scientific American *and* Nature.

MORE TO EXPLORE

Strong Force: The Story of Shirley Ann Jackson. Diane O'Connell. Joseph Henry Press, 2006.

SCIENTIFIC AMERICAN ONLINE
Read a chapter from *Strong Force* at ScientificAmerican/dec2011/jackson

Atewa dinospider (*Ricinoides atewa*) from West Africa



Relics: Travels in Nature's Time Machine

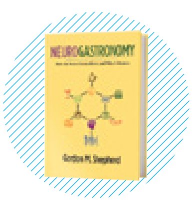
by Piotr Naskrecki. University of Chicago Press, 2011 ($45)

Take a photo safari through the world as it used to be, as revealed by living organisms little changed from their ancient ancestors. Naturalist and photographer Piotr Naskrecki gives creatures ranging from horseshoe crabs on the eastern shores of the U.S. to three-toed sloths in the forests of Guyana their due.

Magical Mathematics: The Mathematical Ideas That Animate Great Magic Tricks

by Persi Diaconis and Ron Graham. Princeton University Press, 2011 ($29.95)

The Riemann hypothesis, the Mandelbrot set, Fermat's last theorem—these mathematical notions and others underlie all manner of magic tricks. Mathematicians Persi Diaconis—also a card magician—and Ron Graham—also a juggler—unveil the connections between magic and math in this well-illustrated volume.



Neurogastronomy: How the Brain Creates Flavor and Why It Matters

by Gordon M. Shepherd. Columbia University Press, 2011 ($24.95)

Making the case that the role of humans' sense of smell in producing flavor has been vastly underappreciated, neuroscientist Gordon M. Shepherd lays out the new science of food perception and upends the received wisdom that the sense of smell diminished over the course of human evolution.

Alone in the Universe: Why Our Planet Is Unique

by John Gribbin. Wiley, 2011 ($25.95)

"There may be more habitable planets in the Galaxy than there are people on planet Earth. But 'habitable' does not mean 'inhabited.'" Astrophysicist John Gribbin describes the cosmic events that have made Earth special and argues that ours is almost certainly the only intelligent civilization in the Milky Way.

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COMMENT AT ScientificAmerican.com/dec2011

Push Flip-Top closed.

Shake.

Push Flip-Top open.

Pour.

Viewing the world with a rational eye

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His new book is *The Believing Brain.* Follow him on Twitter @michaelshermer

Sacred Salubriousness

New research on self-control explains the link between religion and health

Ever since 2000, when psychologist Michael E. McCullough, now at the University of Miami, and his colleagues published a meta-analysis of more than three dozen studies showing a strong correlation between religiosity and lower mortality, skeptics have been challenged by believers to explain why—as if to say, "See, there is a God, and this is the payoff for believing."

In science, however, "God did it" is not a testable hypothesis. Inquiring minds would want to know how God did it and what forces or mechanisms were employed (and "God works in mysterious ways" will not pass peer review). Even such explanations as "belief in God" or "religiosity" must be broken down into their component parts to find possible causal mechanisms for the links between belief and behavior that lead to health, well-being and longevity. This McCullough and his then Miami colleague Brian Willoughby did in a 2009 paper that reported the results of a meta-analysis of hundreds of studies revealing that religious people are more likely to engage in healthy behaviors, such as visiting dentists and wearing seat belts, and are less likely to smoke, drink, take recreational drugs and engage in risky sex. Why? Religion provides a tight social network that reinforces positive behaviors and punishes negative habits and leads to greater self-regulation for goal achievement and self-control over negative temptations.

Self-control is the subject of Florida State University psychologist Roy Baumeister's new book, *Willpower,* co-authored with science writer John Tierney. Self-control is the employment of one's power to will a behavioral outcome, and research shows that young children who delay gratification (for example, forgoing one marshmallow now for two later) score higher on measures of academic achievement and social adjustment later. Religions offer the ultimate delay of gratification strategy (eternal life), and the authors cite research showing that "religiously devout children were rated relatively low in impulsiveness by both parents and teachers."

The underlying mechanisms of setting goals and monitoring one's progress, however, can be tapped by anyone, religious or not. Alcoholics Anonymous urges members to surrender to a "higher power," but that need not even be a deity—it can be anything that helps you stay focused on the greater goal of sobriety. Zen meditation, in which you count your breaths up to 10 and then do it over and over, the authors note, "builds mental discipline. So does saying the rosary, chanting Hebrew psalms, repeating Hindu mantras." Brain scans of people conducting such rituals show strong activity in areas associated with self-regulation and attention. McCullough, in fact, describes prayers and meditation rituals as "a kind of anaerobic workout for self-control." In his lab Baumeister has demonstrated that self-control can be increased with practice of resisting temptation, but you have to pace yourself because, like a muscle, self-control can become depleted after excessive effort. Finally, the authors note, "Religion also improves the monitoring of behavior, another of the central steps of self-control. Religious people tend to feel that someone important is watching them." For believers, that monitor may be God or other members of their religion; for nonbelievers, it can be family, friends and colleagues.

The world is full of temptations, and as Oscar Wilde boasted, "I can resist everything except temptation." We may take the religious path of Augustine in his pre-saintly days when he prayed to God to "give me chastity and continence, but not yet." Or we can choose the secular path of 19th-century explorer Henry Morton Stanley, who proclaimed that "self-control is more indispensable than gunpowder," especially if we have a "sacred task," as Stanley called it (his was the abolition of slavery). I would say you should select your sacred task, monitor and pace your progress toward that goal, eat and sleep regularly (lack of both diminishes willpower), sit and stand up straight, be organized and well groomed (Stanley shaved every day in the jungle), and surround yourself with a supportive social network that reinforces your efforts. Such sacred salubriousness is the province of everyone—believers and nonbelievers—who will themselves to loftier purposes. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/dec2011

Illustration by Gary Musgrave

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column since atmospheric carbon dioxide levels were about 358 parts per million. He also hosts the *Scientific American* podcast Science Talk.

Respect for Evidence

The proof is in the pudding only if you concede the fact of the pudding

The leaves are turning as I write in early October. Also turning is my stomach, from the accounts coming out of something called the Values Voter Summit in Washington, D.C. According to Sarah Posner writing online in Religion Dispatches, talk-radio host Bryan Fischer went out of his way to attack me. And probably you. Anybody, really, who accepts science as an arbiter of reality. Fischer told the assembled that America needs a president who will "reject the morally and scientifically bankrupt theory of evolution."

Evolution is a strange process indeed, to cobble together organisms who so completely and emotionally reject it. Well, evolution concerns itself only with differential survival, and brainpower may not be a crucial factor. Fischer may as well have gotten out of a car at the convention center and proclaimed that the car had not brought him there and did not in fact exist. To thunderous applause. One's only reasonable response to this whole scene is to bring forefinger to mouth and rapidly toggle the lips while humming, so as to produce a sound roughly in accord with a spelling of "Blblblblblblblblblb."

A few days before the summit, over in the rational world, Saul Perlmutter won a share of the 2011 Nobel Prize in Physics. He and his fellow laureates, Adam Riess and Brian Schmidt, showed that the universe is not only expanding, the expansion is accelerating. (On hearing this news, my brother asked me if there was a limit. I told him yes, no more than three people can share any one Nobel Prize.)

Perlmutter's Nobel led to an additional, highly coveted prize. His University of California, Berkeley—home to 22 Nobelists over the years—gives newly minted laureates a campus-wide parking permit. And, if asked, every time Perlmutter exits his car he will no doubt respond that he arrived in it and that it exists.

Perlmutter the driver also surely has the good sense to know that alcohol impairs judgment and neuromuscular skills. Contrast that mind-set with *Miami Herald* reporter Jose Cassola—well, former *Miami Herald* reporter now—who ran a stop sign shortly before Perlmutter was getting news of his Nobel and then told the cop who pulled him over, "You can't get drunk off of vodka."

As Cassola explained to the arresting officer: "I'm fat, I won't be able to get drunk from only seven shots." He later expounded on his unique theories about alcohol and its effects to media-watch reporter Gus Garcia-Roberts of the *Miami New Times:* "Dude, I go to Chili's all the time and have two-for-one margaritas, and then I get in my car. Am I drunk? No!"

The disoriented mind pronouncing itself whole is always a wonder to behold. Which brings us back to the Values Voter Summit. Oddly, Fischer's enraptured audience may have been morphologically identifiable. That notion appears in an article in the June 25, 1885, issue of the journal *Nature* by Charles Darwin's half cousin Francis Galton. (It's probably a good example of our information inundation that less than an hour after I discovered this 126-year-old article, I cannot re-create the steps by which I wound up reading it. E-mail? Twitter? Link within a link? It's all part of the mystery.)

Galton found himself at a boring lecture and decided to study the sea of heads in front of him. He noted that "when the audience is intent each person … holds himself rigidly in the best position for seeing and hearing." In other words, they sit up straight. When the talk got tedious, "the intervals between their faces, which lie at the free end of the radius formed by their bodies, with their seat as the centre of rotation varies greatly." In other words, they lean.

By all accounts, the audience at the Values Voter Summit was sitting ramrod straight, indicating great engagement with the material being presented. Although a scientific mind-set requires a consideration of another possibility: that x-rays would reveal in each attendee a stick responsible for the vertical attitude and in desperate need of removal. SA

SCIENTIFIC AMERICAN ONLINE
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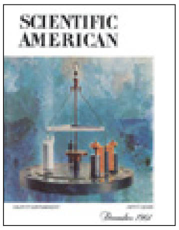
Illustration by Matt Collins

Innovation and discovery as chronicled in *Scientific American*



December 1961

Protein Structure

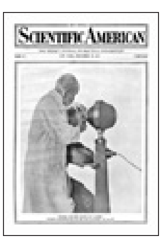
"We looked at something no one before us had seen: a three-dimensional picture of a protein molecule in all its complexity. This first picture was a crude one, and two years later we had an almost equally exciting experience, extending over many days that were spent feeding data to a fast computing machine, of building up by degrees a far sharper picture of this same molecule. The protein was myoglobin, and our new picture was sharp enough to enable us to deduce the actual arrangement in space of nearly all of its 2,600 atoms. —John C. Kendrew"

Kendrew shared the 1962 Nobel Prize in Chemistry for this work.

Milgram on Conformity

"My objective was to see if experimental techniques could be applied to the study of national characteristics, and in particular to see if one could measure conformity in two European countries: Norway and France. Conformity was chosen for several reasons. First, a national culture can be said to exist only if men adhere, or conform, to common standards of behavior; this is the psychological mechanism underlying all cultural behavior. Second, conformity has become a burning issue in much of current social criticism; critics have argued that people have become too sensitive to the opinions of others, and that this represents an unhealthy development in modern society. Finally, good experimental methods have been developed for measuring conformity. —Stanley Milgram"

The complete article is available at www.ScientificAmerican.com/dec2011/milgram



December 1911

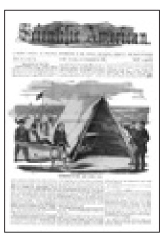
Presidential Letter

"To the Editor of the *Scientific American:* Until peaceful means of settling all International Controversies are assured to the World, prudence and patriotism demand that the United States maintain a navy commensurate with its wealth and dignity. —Wm. H. Taft. Letter from President Taft, Commander-in-Chief of the U.S. Navy."

Printed in the special issue on the Navy.

Gnathological Observation

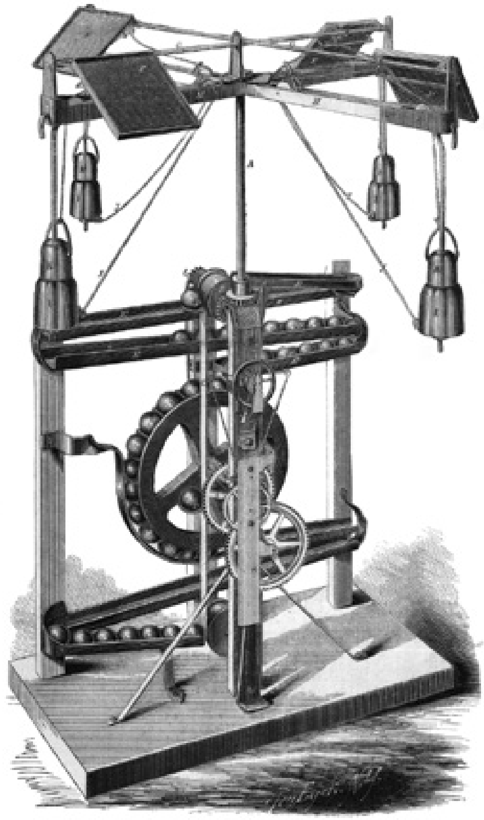
"To determine the average strength of the jaws, Dr. G. E. Black, president of the Chicago Dental University, devised an instrument of very simple design but with a name that would put the average jaw to a severe test—the gnathodynamometer. With this instrument he made tests of the bite strength of a thousand persons. The average showed 171 pounds for the molar teeth and much less for bicuspids and incisors. The list of subjects includes men and women of all classes, from a blacksmith to a Chinese laundryman."



December 1861

A Mighty Wind

"One of the great forces nature furnished to man without any expense, and in limitless abundance, is the power of the wind. Many efforts have been made to obtain a steady power from the wind by storing the surplus from when the wind is strong. One of the latest and simplest of these is illustrated in the accompanying engraving. A windwheel is employed to raise a quantity of iron balls, and then these balls are allowed to fall one by one into buckets upon one side of a wheel, causing the wheel to rotate, and thus to drive the machine."



Harness the wind: Rube Goldberg in form, basic physics in function, 1861. The iron balls the machine used would have made a fearsome din.

SCIENTIFIC AMERICAN, VOL. V, NO. 25; DECEMBER 21, 1861

Patents

"From inquiries repeatedly made of us as to who are the legitimate owners of inventions issued under various circumstances, a few items of information under this head will interest our inventor readers at least. In regard to inventions made by slaves, it has been the practice of the Patent Office to reject such applications, as they are considered legally incompetent alike to receive the patent and to transfer their interest to others. In reference to free colored men, we believe them also to be incompetent to receive a patent, as under the United States Laws they are not regarded as citizens, and could not therefore defend a patent against infringers in the United States courts."

The Dred Scott decision of 1857 that legalized this situation was nullified by the Thirteenth, Fourteenth and Fifteenth amendments to the Constitution.

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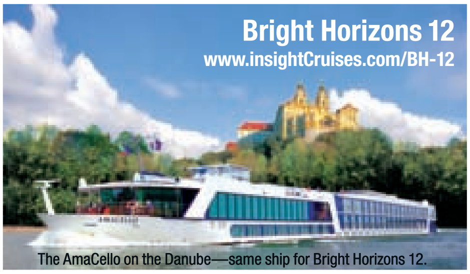


The AmaCello on the Danube—same ship for Bright Horizons 12.

RHINE RIVER CRUISE

April 12–20, 2012

Curious how magic works? Ready to absorb the latest science, without distraction? Join Scientific American for current science and immersion into German culture and scenic beauty, on a river cruise sailing from Amsterdam, The Netherlands, to Basel, Switzerland on AMA Waterways's AmaCello, April 12–20, 2012. Particle physics, cognitive neuroscience, solar science, and alpine archaeology are on our itinerary, along with medieval German cities and Strasbourg, France.

Take a close look at sensory perception and visual illusions. Dig into medicine in the ancient world and the interplay of natural and physical sciences in archaeology. Illuminate the profound Sun-Earth connection. Capture evolving thought in subatomic physics. You can lose yourself in the rich intricacies of science while the AmaCello and its English-speaking staff provide gracious service, comfortable quarters, and superb regional cuisine.

Bright Horizons 12 offers distilled cutting-edge science and local brews together with long-awaited relaxation with good friends. You can add even more Aha! moments to your itinerary with an optional post-cruise excursion to CERN, or find your inner Parisian on an optional 1-, 2-, or 3-day post-cruise visit to the City of Lights.

Sampling of Topics

- PARTICLE PHYSICS
- SOLAR SCIENCE
- COGNITIVE NEUROSCIENCE
- ALPINE ARCHAEOLOGY

The cruise fare starts at $3,098 for a Category D cabin, per person. The Bright Horizons Program costs $1,195. Taxes and fees are $199 per person. Gratuities are €105.

ALASKA

June 8–15, 2012

What awaits you in Alaska on Bright Horizons 14? The Great Land and Scientific American present legacies and frontiers for your enjoyment. Based on Celebrity Cruises' m.s. Infinity, roundtrip Seattle June 8–15, 2012, we head up the Inside Passage and get the inside scoop on the Hubble Space Telescope, geospatial imaging, particle physics at CERN, and social psychology. Sail into a state of Native cultures, Gold Rush history, and rich, diverse habitats.

Powered by the midnight sun, surrounded by purple mountain majesty, explore the complex terrain of emotion and consciousness with Dr. John Cacioppo. Get details on the big picture of geospatial imaging with Dr. Murray Felsher. Catch up on particle physics at CERN with Dr. James Gillies. Get a firsthand account of life on the space station with astronaut Dr. Steven Hawley. Peer into the past and future of telescopic space exploration with Dr. Stephen Maran. Launch your Bright Horizons 14 fun with an optional pre-cruise sortie to the Museum of Flight in Seattle.

Connect to the science community on Bright Horizons 14. Inhale Alaska's unabashed outdoorsy spirit. Enjoy Native art and historic places. Sample unrivaled birdwatching. Glimpse bears on the beach and whales in the waves. Share glacier-watching and hot cocoa with a friend. Bring home the latest in the world of science.

Sampling of Topics

- PLANETARY SCIENCE
- COGNITIVE SCIENCE
- PARTICLE PHYSICS
- GEOSPATIAL IMAGING
- SPACE EXPLORATION

Cruise prices start at $959. The Bright Horizons Program costs $1,475. Government taxes and fees total $464 per person. Gratuities are $105 per person (a little more for Suite cabins).

For more info please call 650-787-5665
or email Concierge@InSightCruises.com

EAST MEDITERRANEAN

October 25 – November 5, 2012

Been there, done that? Think again! Italy, Turkey, Israel, and Greece have drawn explorers over the span of 5,000 years. Bright Horizons is heading in to experience the region through new eyes, new data, and new discoveries as Classical cultures and cutting-edge science converge in the Eastern Mediterranean. Share in the new thinking required by a changing world on Bright Horizons 15 aboard the Costa Mediterranea, roundtrip Genoa, Italy, October 25–November 5, 2012.

Face the challenges posed by conservation planning and wildfire management, guided by Dr. Yohay Carmel. Dive into discoveries in astro-particle physics with Dr. David Lunney. Glimpse the neuroscience behind sensory perception and visual illusions with Drs. Stephen Macnik and Susana Martinez-Conde. Focus on developments in the nature and maintenance of memory with Dr. Jeanette Norden. Take in evolving thought on humankind's emigration from Africa with Professor Chris Stringer.

Discover the possibilities in environmental and neuroscience, particle physics and anthropology. Visit archaeological sites and imagine the finds to come. Soak in the Mediterranean lifestyle. Savor the cuisine of Genoa. If you're game for field trips, we've designed behind-the-scenes experiences to extend your fun, from CERN in Geneva to fascinating Herodium in Palestine. Send your questions to concierge@insightcruises.com or call 650-787-5665 with your questions. Please join us!

Sampling of Topics

- NUCLEAR ASTROPHYSICS
- NEUROSCIENCE MEMORY
- COGNITIVE NEUROSCIENCE
- CLIMATOLOGY
- HUMAN EVOLUTION

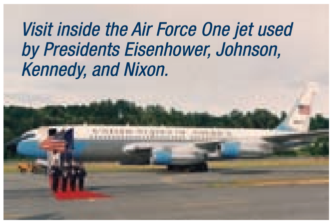
Cruise prices vary from $1,299 for an Interior Stateroom to $4,499 for a Grand Suite, per person. The Bright Horizons Program costs $1,475. Government taxes and fees are $299 per person. Gratuities are $11 per person per day.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

INSIDER'S TOUR OF CERN

April 20, 2012 and October 22, 2012

From the tiniest constituents of matter to the immensity of the cosmos, discover the wonders of science and technology at CERN. Join Bright Horizons for a private, custom, full-day tour of this iconic facility. Whether you lean toward concept or application, there's much to pique your curiosity. Discover the excitement of fundamental research and get an insider's look at the world's largest particle physics laboratory. Our full day will be led by a CERN physicist. We'll have an orientation; visit an accelerator and experiment; get a sense of the mechanics of the Large Hadron Collider (LHC); make a refueling stop for lunch; and have time to peruse exhibits and media on the history of CERN and the nature of its work.

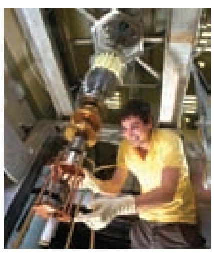

Visit inside the Air Force One jet used by Presidents Eisenhower, Johnson, Kennedy, and Nixon.

THE MUSEUM OF FLIGHT

June 7, 2012

If you love vapor trails in the wild blue yonder and the thrill of takeoff, join Insight Cruises in a day of fun and learning at the Museum of Flight at legendary Boeing Field near Seattle. Go behind the scenes with the Senior Curator. Explore The Boeing Company's original manufacturing plant. Get the big picture of aviation in the 3 million cubic-foot, six-story Great Gallery. An aviation historian will discuss the engineering and courage that took us from straight-wing planes to swept-wing jets. We'll do a refueling stop with a catered lunch provided by McCormick and Schmick's. After lunch, off we go into the Museum's Personal Courage Wing, followed by a talk on the development of aircraft carriers, and their technology and tactical use.

Please join us for an uplifting journey through aeronautical innovation. You may see the ubiquitous float planes of the great Northwest in a different perspective!

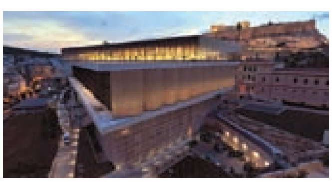


HAIFA & THE TECHNION

October 29, 2012

Perched on the Mediterranean, the Haifa region encapsules the ancient history and cutting-edge science, cultures, and beliefs that say "Israel." Get a context for Israel on a full-day visit that is equal parts cultural introduction and science field trip.

We start our day with a nod to the spiritual at the golden-domed Bahai Shrine, the world center of the Bahai faith renowned for 19 stunningly landscaped terrace gardens, and a UNESCO World Heritage site. Off next to the Technion, where Yohay Carmel, Ph.D., Professor of Civil and Environmental Engineering at the Technion (Israel Institute of Technology), along with some of his Technion associates, will direct our private tour of the Technion campus and research facilities.



ATHENS **November 1, 2012**

The Parthenon and its Acropolis setting are stunning, no doubt about it. They don't require interpretation, and compose the perfect DIY Athens excursion. On the other hand, visiting the new Acropolis Museum and the National Archaeological Museum with a skilled guide who's on your wavelength adds immeasurably to the experience. We suggest you join Bright Horizons on a focused trip. You'll see the Parthenon frieze, exquisite sanctuary relics, and Archaic sculpture at the Acropolis Museum (picture left; as you can see, the museum sits just below the Acropolis).

Lunch, of course, is tucked away at a taverna favored by Athenian families. For dessert, we'll visit the richest array of Greek antiquities anywhere—at the National Archaeological Museum.

CST# 2065380-40

For information on more trips like this, please visit
scientificamerican.com/travel

Cognitive Neuroscience, cont.

Windows on the Mind

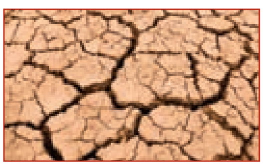
What's the connection behind eye movements and subliminal thought? Join Dr. Macknik and Dr. Martinez-Conde in a look at the latest neurobiology behind microsaccades, the involuntary eye movements that relate to perception and cognition. Learn how microsaccades suggest bias toward certain objects, their relationship to visual illusions, and the pressing questions spurring visual neurophysiologists onward.

Champions of Illusion

The study of visual illusions is critical to understanding the basic mechanisms of sensory perception and advancing cures for visual and neurological diseases. Connoisseurs of illusion, Dr. Macknik and Dr. Martinez-Conde produce the annual Best Illusion of the Year Contest. Study the most exciting novel illusions with them and learn what makes these brain tricks work.

Sleights of Mind

Magic fools us because humans have hardwired processes of attention and awareness that can be "hacked." A good magician employs the mind's own intrinsic properties. Magicians' insights, gained over centuries of informal experimentation, have led to new discoveries in the cognitive sciences, and reveal how our brains work in everyday situations. Get a front-row seat as the key connections between magic and the mind are unveiled!



CLIMATOLOGY

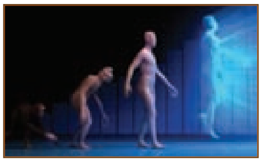
Speaker: Yohay Carmel, Ph.D.

Prioritizing Land for Nature Conservation: Theory and Practice

Forest clearing, climate change, and urban sprawl are transforming our planet at an accelerating rate. Conservation planning prescribes principles and practical solutions for selecting land for protection, assigning land for development, and minimizing the negative impact on nature. Taking a bird's-eye view of approaches to conservation, we'll put the hot topics and tough questions in perspective through an insightful discussion.

Facing a New Mega-Fire Reality

Worldwide, the area, number, and intensity of wildland fires has grown significantly in the past decade. Fire-protection strategies used in the past may not work in the future. Learn the roots and causes of wildfires and recent efforts to predict, manage, and mitigate fire risk. Gain food for thought about the complex interface between science and policy.



HUMAN EVOLUTION

Speaker: Chris Stringer, Ph.D.

Human Evolution: the Big Picture

Time-travel through 6 million years of human evolution, from the divergence from African apes to the emergence of humans. In 1871, Charles Darwin suggested that human evolution had begun in Africa. Learn how Darwin's ideas stand up to the latest discoveries, putting his tenets into context and perspective.

The First Humans

About 2 million years ago the first humans appeared in Africa, distinctly different from their more ancient African ancestors. Discover what drove their evolution and led to a spread from their evolutionary homeland to Asia and Europe. Explore current thinking on the early stages of human evolution.

The Neanderthals: Another Kind of Human

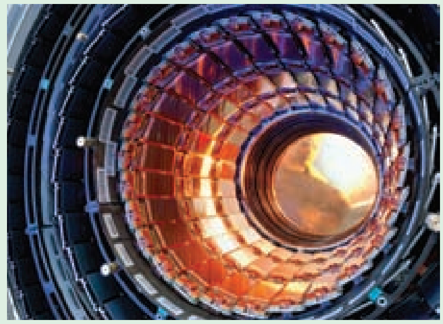
Our close relatives, the Neanderthals, evolved in parallel with *Homo sapiens*. Often depicted as bestial ape-men, in reality they walked upright as well as we do, and their brains were as large as ours. So how much like us were they? What was their fate? Track the evolution of the Neanderthals in light of the latest discoveries.

The Rise of *Homo Sapiens*

Modern humans are characterized by large brains and creativity. How did our species arise and spread across the world? How did we interact with other human species? We will examine theories about modern human origins, including Recent African Origin ("Out of Africa"), Assimilation, and Multiregional Evolution, and delve in to the origins of human behavioral traits.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

INSIDER'S TOUR OF CERN



Pre-cruise: October 22, 2012—From the tiniest constituents of matter to the immensity of the cosmos, discover the wonders of science and technology at CERN. Join Bright Horizons for a private full-day tour of this iconic nuclear-research facility.

Whether you lean toward concept or application, there's much to pique your curiosity. Discover the excitement of fundamental research and get an insider's look at the world's largest particle physics laboratory.

Our full-day tour will be led by a CERN physicist. We'll have an orientation, visit an accelerator and experiment, get a sense of the mechanics of the large hadron collider (LHC), make a refueling stop for lunch, and have time to peruse exhibits and media on the history of CERN and the nature of its work.

This tour includes: Bus transfer from Geneva, Switzerland to our Genoa, Italy hotel (October 23) • 3 nights' hotel (October 20, 21, 22) • 3 full breakfasts (October 21, 22, 23) • Transfers to and from the hotel on tour day (October 22) • Lunch at CERN • Cocktail party following our CERN visit • Do-as-you-please day in Geneva, including transfers to and from downtown (October 21) • Transfer from airport to our Geneva hotel

The price is $799 per person (based on double occupancy). This trip is limited to 50 people. NOTE: CERN charges no entrance fee to visitors.

EPHESUS

November 1, 2012—Many civilizations have left their mark at Ephesus. It's a complex and many-splendored history, often oversimplified. Bright Horizons pulls together three important aspects of understanding Ephesus that are rarely presented together. You'll meander the Marble Road, visit the legendary latrines, check out the Library, and visit the political and commercial centers of the city. A visit to the Terrace Houses will enhance your picture of Roman-era Ephesus.

We'll take a break for Mediterranean cuisine in the Selcuk countryside, then visit the Ephesus Museum in Selcuk, where city excavation finds are showcased, and you'll get a fuller look at local history, from the Lydians to the Byzantines.

ATHENS

November 1, 2012—The Parthenon and its Acropolis setting are stunning, no doubt about it. Requiring no interpretation, they are ideal for a DIY Athens excursion. On the other hand, visiting the new Acropolis Museum and the National Archaeological Museum with a skilled guide who's on your wavelength adds immeasurably to the experience. We suggest you join Bright Horizons on a focused trip. You'll see the Parthenon frieze, exquisite sanctuary relics, and Archaic sculpture at the Acropolis Museum (as you can see from the picture, the museum sits just below the Acropolis).

Lunch is tucked away at a taverna favored by Athenian families. For dessert, we'll visit the richest array of Greek antiquities anywhere—at the National Archaeological Museum.

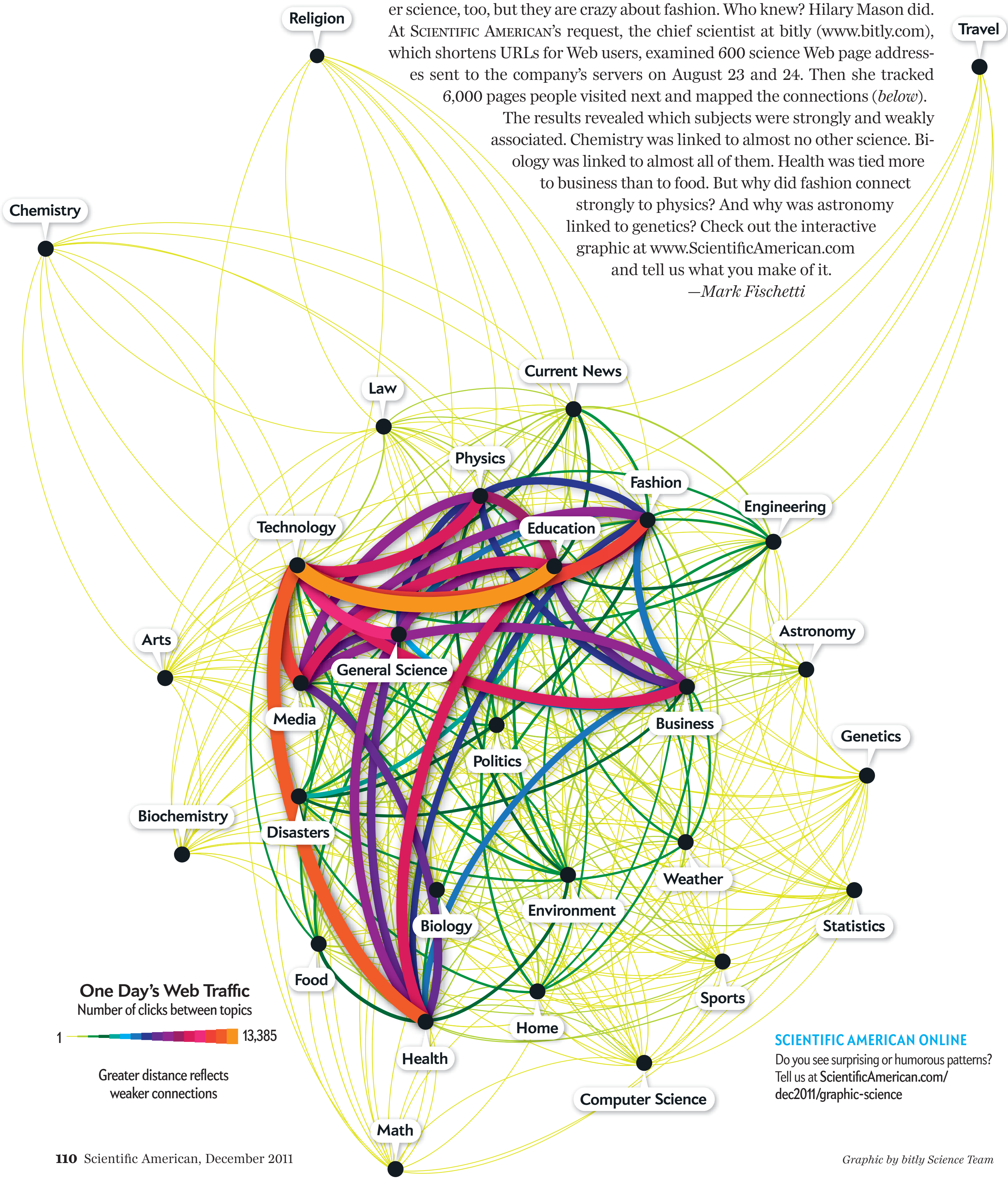
The Links We Love

Science aficionados have odd and surprising interests

People who are intrigued with physics are somewhat intrigued with computer science, too, but they are crazy about fashion. Who knew? Hilary Mason did. At Scientific American's request, the chief scientist at bitly (www.bitly.com), which shortens URLs for Web users, examined 600 science Web page addresses sent to the company's servers on August 23 and 24. Then she tracked 6,000 pages people visited next and mapped the connections (*below*).

The results revealed which subjects were strongly and weakly associated. Chemistry was linked to almost no other science. Biology was linked to almost all of them. Health was tied more to business than to food. But why did fashion connect strongly to physics? And why was astronomy linked to genetics? Check out the interactive graphic at www.ScientificAmerican.com and tell us what you make of it.

—Mark Fischetti



SCIENTIFIC AMERICAN ONLINE
Do you see surprising or humorous patterns? Tell us at ScientificAmerican.com/dec2011/graphic-science

Graphic by bitly Science Team


"Affordable energy."
"Cleaner energy."
"A job when I graduate."
Who's right? They all are. That's why, at ConocoPhillips, we're helping to power America's economy by safely accessing one of America's most abundant energy resources: natural gas. Which creates jobs. Reduces emissions. And answers each of their concerns.
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