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THE FIRST AMERICANS

Trailblazers arrived far earlier than previously thought. Who were they?

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SCIENTIFIC AMERICAN

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ON THE COVER

For years the conventional wisdom on the peopling of the New World held that the so-called Clovis hunters were the first Americans, arriving some 13,000 years ago. Now new evidence shows conclusively that humans reached the Americas far earlier than previously thought, raising a host of questions about who these pioneers were and how they got here. Image by Viktor Deak.

FEATURES

Photograph by David Liittschwager

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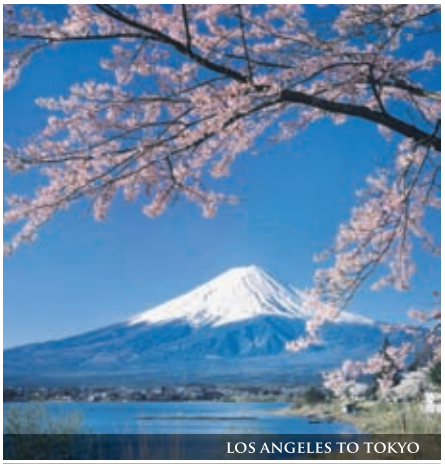
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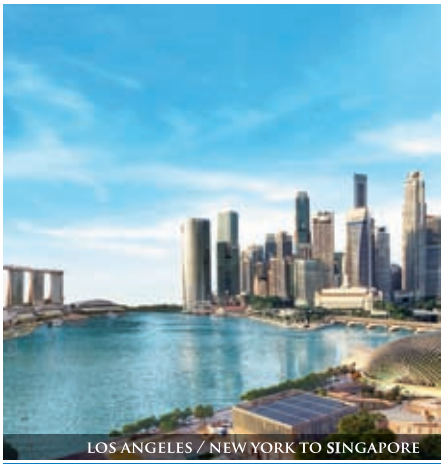
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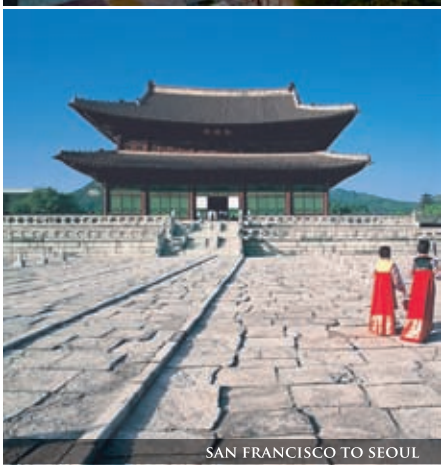
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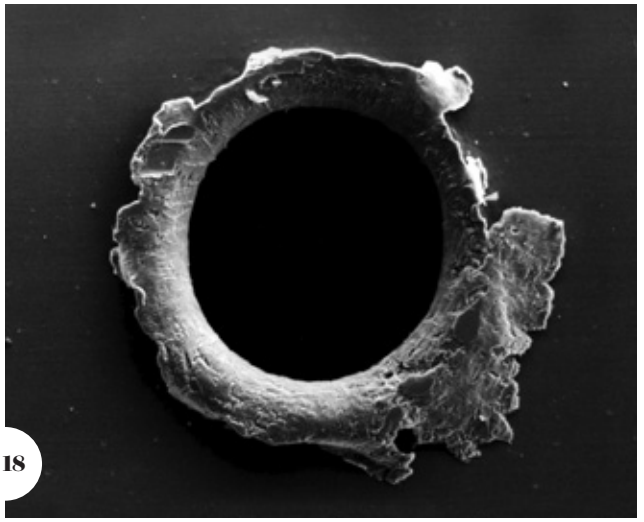

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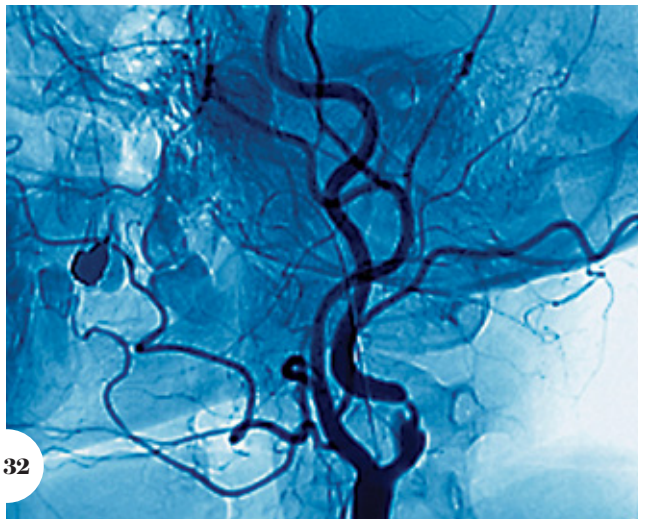

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DEPARTMENTS

ON THE WEB

Planetary Science Gets Worldly
Astronomers and planetary scientists recently met in France to share the latest research on the solar system and on distant extrasolar worlds. The joint session of U.S. and European organizations drew attendees from all over this planet. *Go to www.ScientificAmerican.com/nov2011/planets*

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

Paths Taken

ONE OF THE PLEASURES OF *SCIENTIFIC AMERICAN,* I've always thought, is that it offers armchair travelers a vicarious expedition to the exciting worlds uncovered through science. I reflected on that fact recently as I sat on the tarmac, my flight 23rd in line for takeoff at LaGuardia Airport in New York City. I was reading over this issue's articles and again became absorbed by our cover story, "The First Americans," by Heather Pringle. Time rolled back in my mind's eye, and I imagined a wholly different journey than the one I was taking.

What might it have been like to step across Beringia, the bridge between Asia and the Americas, during the last ice age? You are wearing warm, tailored clothing of hides, stitched together with bone needles. You are expert at reading the land for clues about the presence of prey and edible vegetation. Massive ice sheets cover much of your Arctic world. One day, ahead of you, you see a grassy plain—the dry winds whistling across it have made snowfall scant. Behind you are campfires, but none lie ahead. Drawn by the open path and the promise of richer hunting, you step toward a New World.

Studies of genetics and the recently discovered trove of more than 19,000 stone tools and other evidence from 15,500 years ago are helping scientists piece together those trailblazers' paths and what their lives were like. The findings indicate that humans arrived thousands of years earlier than previously thought. Turn to page 36 for more on this detective story.

Other science excursions in this issue include going to the Red Planet ("Digging Mars," on page 46), to Central America and elsewhere to battle dengue ("The Wipeout Gene," on page 68), and to the frontiers of medicine ("The Medical Sleuth," on page 86).

Harvard University economist Edward Glaeser (*left*).

As for me, I was headed to Washington, D.C., where we held a reception with policy leaders on Capitol Hill to celebrate the magazine's September single-topic issue on cities. Joining me was Harvard University economist Edward Glaeser, author of two pieces, who spoke about how, done right, with an emphasis on education, the greater density of humanity afforded by urban living can help us innovate our way out of the problems facing us today. That's a journey we'll all be making together. SA

COURTESY OF DARREN SANTOS

Illustration by Nick Higgins

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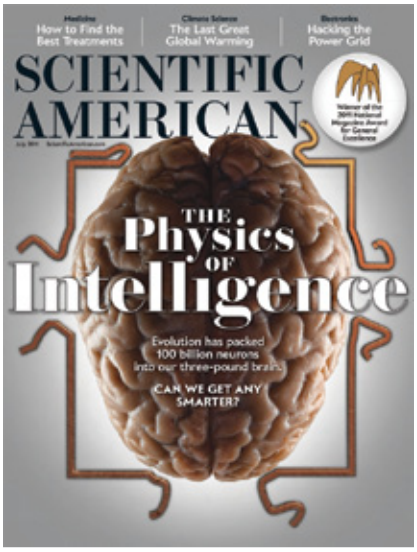

July 2011

TRIAGING TREATMENTS

The problems with the U.S. health care system described by Sharon Begley in "The *Best* Medicine" are accurate. It is gratifying that the National Institutes of Health is finally willing to fund real comparative effectiveness research. But the NIH, under pressure from Congress, has been reluctant to fund studies directly comparing the costs of competing treatments. I retired from the medical research field in part because of this refusal to look for the most effective and least costly answers and to support research on how to reduce unnecessary care.

Why is serious cost control not a part of either political party's health care "reform" plans? To get elected, one must accept money from the very groups that require reform and regulation. Consequently, we get cosmetic reforms that never address the real issues that double the cost of health care. Instead reductions in care to the aged and poor are the preferred cost-control mechanisms. Until voters are freed from the election propaganda of special interests, the U.S. will continue to have the world's most costly and least efficient health care system and the worst health care outcomes of any developed nation.

THOMAS M. VOGT
Bountiful, Utah

BLEMISH OR BOON?

In "Evolution of the Eye," Trevor Lamb draws together multiple lines of evidence to create a persuasive narrative for the early evolution of the vertebrate eye. But is it fair to equate historical constraints with defects in describing how vertebrate photoreceptors are on the back of the "inside-out" retina, shadowed by blood vessels and overlying cells? Has a possible advantage to this arrangement been ruled out?

DONALD ROBINSON
Vancouver, B.C.

LAMB REPLIES: There are indeed clear advantages that presumably led the eye vesicle to fold inward during evolution. This infolding put the photoreceptors in close proximity to the retinal pigment epithelium, enabling the biochemical recycling of retinoids following light absorption, the attenuation of light that passes through the photoreceptors unabsorbed, and the delivery of oxygen and nutrients from the overlying choroid tissue. Other by-products of this infolding remain as "scars" of evolution, however.

BLACK HOLES REVISITED

In Peter Byrne's interview with Leonard Susskind, "The Bad Boy of Physics," Susskind insists that reality may forever be beyond reach of our understanding, partly because of his principle of black hole complementarity, which holds that there is an inherent ambiguity in the fate of objects that fall into a black hole. From the object's point of view, it passes the hole's perimeter and is destroyed at the singularity at its center. To an external observer, it is incinerated at the event horizon. It seems clear that this apparent ambiguity stems from the fact that—according to general relativity—the passage of time differs for the object and observer.

What actually happens is that from the vantage point of the observer, the object appears "frozen in time" when it arrives at the event horizon (and permanently disappears from view upon the horizon's expansion). One should not conclude that the object's fate is ambiguous. The event is merely observed in a different way depending on the observer's frame of reference.

ANTHONY TARALLO
The Hague, the Netherlands

SUSSKIND REPLIES: Tarallo provides a succinct account of how classical relativists described matter falling into a black hole before the early 1970s. The problem with that view dates back to Stephen Hawking's discovery that the combination of quantum mechanics and general relativity implies that black holes evaporate. As Hawking emphasized, if bits of matter "permanently disappear from view," then that evaporation leads to a contradiction with those rules. His solution was to give up the standard rules of quantum mechanics, but after two decades of confusion a consensus emerged that Hawking was wrong. Today the highly unintuitive black hole complementarity and holographic principles are central pillars of the quantum theory of gravity.

The event is indeed observed in a different way depending on the observer's frame of reference. That is how two apparently contradictory things can both occur.

I would like to clarify that "reality may forever be beyond reach of our understanding" is a stronger statement than I intended. What I wanted to convey is that the hardwired concepts that evolution equipped us with are not suitable for visualizing the strange and unintuitive behavior of the quantum world, let alone the quantum-gravity world. Still, physicists have been very good at rewiring their circuits by means of abstract mathematics, which must replace old ways of visualizing the world each time we encounter something radically new.

USING YOUR BRAIN

In "The Limits of Intelligence," Douglas Fox points out that human intelligence is limited by communication among neurons in the brain, which is limited in turn by the size of our neurons. "The human mind, however," Fox writes, "may have better ways of expanding without the need for further biological evolution." He goes on to suggest social interactions as a means to

"Why is serious cost control not a part of either party's health care 'reform' plans?"

THOMAS M. VOGT *BOUNTIFUL, UTAH*

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pool our intelligence with others. What Fox forgets to point out, however, is that as a species we have not yet learned to use our individual brains to full capacity. In fact, a typical person uses only about 10 percent of his or her brain. Rather than dwelling on the constraints imposed on the human mind by nature, wouldn't it be more useful—as well as smarter—to figure out ways to boost and strengthen existing neuronal connections in our brains, thereby making the most of what we already possess?

ANDREA ROTHMAN
Great Neck, N.Y.

FOX REPLIES: It has been estimated that only 1 to 15 percent of neurons in the human brain are firing at any given instant. But it does not necessarily follow that we could use the other 90 percent or so of our neurons and suddenly be smarter. Letting most of our neurons lie idle most of the time is a design principle that has evolved into our brain. Having neurons lie idle uses a lot less energy than having them spike—and so having lots of neurons that you do not use all that often actually maximizes the ratio of information processed to energy spent.

For example, the more neurons you have, the more pathways any particular nerve spike can travel. So each nerve spike inherently contains more information—and your brain can get away with firing fewer of those energy-expensive spikes. Even if you discounted all of the above and obstinately started firing every neuron in your brain every second, you would still have to pay for all those extra energy-hungry spikes, and it could easily double or quadruple the calories your brain consumes. In other words, nothing is free. The brain we have is almost certainly evolved for maximum information per energy spent.

ERRATUM

In "Radical Energy Solutions," which appeared in the May issue, the item entitled "Magnetic Air Conditioners" misspoke on two points: Ames Laboratory developed magnetocaloric alloys on its own, not in collaboration with Astronautics Corporation of America. Also, in Astronautics's technology, the alloy disk is not surrounded by a permanent magnet; it passes through a gap in the magnet.

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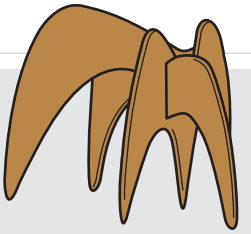

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at ScientificAmerican.com/nov2011

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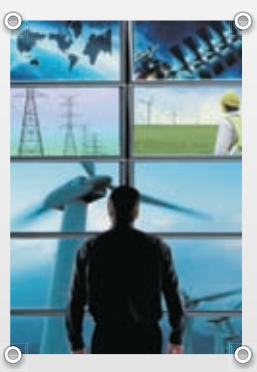

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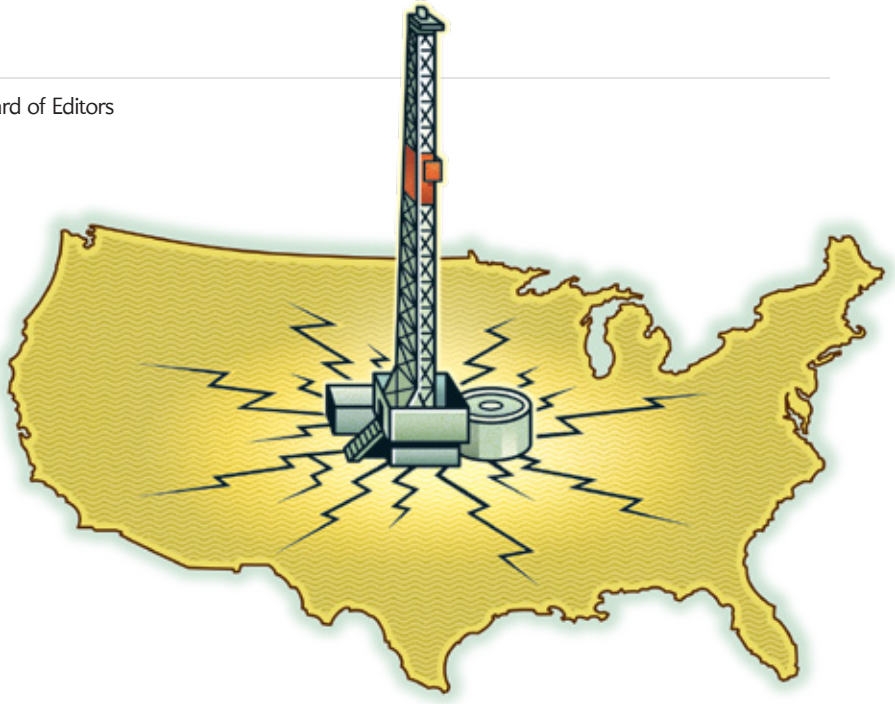


Safety First, Fracking Second

Drilling for natural gas has gotten ahead of the science needed to prove it safe

A decade ago layers of shale lying deep underground supplied only 1 percent of America's natural gas. Today they provide 30 percent. Drillers are rushing to hydraulically fracture, or "frack," shales in a growing list of U.S. states. That is good news for national energy security, as well as for the global climate, because burning gas emits less carbon dioxide than burning coal. The benefits come with risks, however, that state and federal governments have yet to grapple with.

Public fears are growing about contamination of drinking-water supplies from the chemicals used in fracking and from the methane gas itself. Field tests show that those worries are not unfounded. A Duke University study published in May found that methane levels in dozens of drinking-water wells within a kilometer (3,280 feet) of new fracking sites were 17 times higher than in wells farther away. Yet states have let companies proceed without adequate regulations. They must begin to provide more effective oversight, and the federal government should step in, too.

Nowhere is the rush to frack, or the uproar, greater than in New York. In July, Governor Andrew Cuomo lifted a ban on fracking. The State Department of Environmental Conservation released an environmental impact statement and was to propose regulations in October. After a public comment period, which will end in early December, the department plans to issue regulations, and drilling most likely will begin. Fracking is already widespread in Wyoming, Colorado, Texas and Pennsylvania.

All these states are flying blind. A long list of technical questions remains unanswered about the ways the practice could contaminate drinking water, the extent to which it already has, and what the industry could do to reduce the risks. To fill this gap, the U.S. Environmental Protection Agency is now conducting comprehensive field research. Preliminary results are due in late 2012. Until then, states should put the brakes on the drillers. In New Jersey, Governor Chris Christie set an example in August when he vetoed a bill that would permanently ban fracking, then approved a one-year moratorium so his state could consider the results of federal studies. The EPA, for its part, could speed up its work.

In addition to bringing some rigor to the debate over fracking, the federal government needs to establish common standards. Many in the gas industry say they are already sufficiently regulated by states, but this assurance is inadequate. For example, Pennsylvania regulators propose to extend a well operator's liability for water quality out to 2,500 feet from a well, even though horizontal bores from the central well can stretch as far as 5,000 feet.

Scientific advisory panels at the Department of Energy and the EPA have enumerated ways the industry could improve and have called for modest steps, such as establishing maximum contaminant levels allowed in water for all the chemicals used in fracking. Unfortunately, these recommendations do not address the biggest loophole of all. In 2005 Congress—at the behest of then Vice President Dick Cheney, a former CEO of gas driller Halliburton—exempted fracking from regulation under the Safe Drinking Water Act. Congress needs to close this so-called Halliburton loophole, as a bill co-sponsored by New York State Representative Maurice Hinchey would do. The FRAC Act would also mandate public disclosure of all chemicals used in fracking across the nation.

Even the incomplete data we now have suggest specific safety measures. First, the weakest link in preventing groundwater contamination is the concrete casing inside well bores [see "The Truth about Fracking," by Chris Mooney, on page 80]. Inspection of casings should be legally required. Second, the toxic fluid that is a major by-product of fracking is routinely stored in open pits, which can overflow or leach into the soil. It should be stored in tanks instead. Third, gas companies should inject tracers with the fracking fluid so inspectors can easily see whether any of the fluid ends up in the water streaming from residents' faucets. Finally, companies or municipalities should have to test aquifers and drinking-water wells for chemicals *before* drilling begins and then as long as gas extraction continues, so changes in groundwater are obvious.

It is in the industry's interest to accept improved oversight. Public opinion is turning against fracking. That is unfortunate, because more natural gas could benefit everyone. With basic precautions, we can enjoy both cleaner energy and clean water. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/nov2011

Illustration by Peter and Maria Hoey

Here's some quality reading regarding long-term quality.

J.D. Power and Associates ranks Fusion highest in dependability.

Sure, some of our competitors' devoted fans may simply dismiss this information and turn the page, in which case they are now most likely reading a simpler, more easily palatable ad for, say, deodorant body spray. And while it's sad to see them go,

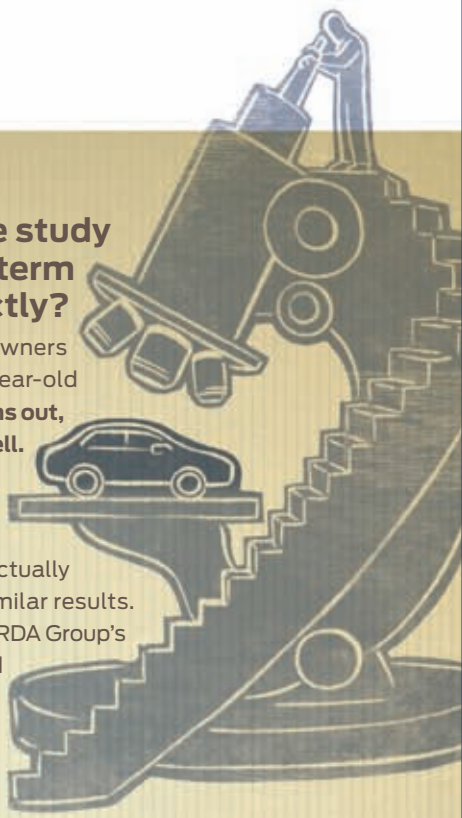
we realize there's just no getting through to some people. Admittedly, those aren't the folks we're speaking to anyway.

No, we're speaking to more **open-minded individuals.**

The sort of individuals who would be pleased to hear that in the J.D. Power and Associates study of nearly 44,000 drivers, Fusion long-term quality measured highest in its class, making it the "Most Dependable Midsize Car."*

How did the study measure long-term quality, exactly?

By measuring problems owners have had with their three-year-old vehicles in the past year. **Turns out, Fusion did quite well.**



And while some may believe this is a flash-in-the-pan sort of 15 minutes for the Fusion, this is actually one of several surveys with similar results. In fact, for **three straight years**, RDA Group's GQRS cumulative survey found **Fusion quality can't be beat** by Camry and Accord.**

Still, though, whom do we expect will be this interested in long-term quality? Well, people who care just as much about it as we do at Ford.

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People who want to know every detail. As much as they possibly can. Who will look over everything, multiple times, to ensure they're making a well-informed decision. **Detail-oriented** people. People, much like yourself, who are still reading.

So go ahead and carefully review the Ford Fusion. Then we invite you to look at the competition too. And after you've done that, **we look forward to meeting you.**

FORD **FUSION**

For more Fusion details and reactions from real Fusion owners, visit ford.com.

*The Ford Fusion received the lowest number of problems per 100 vehicles among midsize cars in the proprietary J.D. Power and Associates 2011 Vehicle Dependability Study.℠ Study based on 43,779 consumer responses measuring problems consumers experienced in the past 12 months with three-year-old vehicles (2008 model-year cars and trucks). Proprietary study results are based on experiences and perceptions of consumers surveyed October-December 2010. Your experiences may vary. Visit jdpower.com.** Based on RDA Group's GQRS cumulative survey at three months of service in three surveys of 2010 Ford competitive owners conducted 9/09-5/10.

Ford

Drive one.

Commentary on science in the news from the experts

Scott Borg is director of the U.S. Cyber Consequences Unit, which is an independent, nonprofit research institute.

A Cybersecurity Nightmare

We can't keep malware out of our computers if we can't find it

The world of cybersecurity is starting to resemble a paranoid thriller. Shadowy figures plant malicious software, or "malware," in our computers. They slip it into e-mails. They transmit it over the Internet. They infect us with it through corrupted Web sites. They plant it in other programs. They design it to migrate from device to device—laptops, flash drives, smartphones, servers, copy machines, iPods, gaming consoles—until it's inside our critical systems. As even the most isolated systems periodically need new instructions, new data or some kind of maintenance, any system can be infected.

The effect could be devastating. After lying dormant for months or years, malware could switch on without any action on the part of those who launched it. It could disable emergency services, cause factories to make defective products, blow up refineries and pipelines, poison drinking water, make medical treatments lethal, wreck electric generators, discredit the banking system, ground airplanes, cause trains to collide, and turn our own military equipment against us.

Many public officials are now aware that something needs to be done. Putting aside worries about privacy and civil liberties, they propose giant government programs to search our critical computer systems and scan everything that goes into them.

But here's where the plot thickens. We don't actually know how to scan for malware. We can't stop it, because we can't find it. We can't always recognize it even if we are looking right at it.

Like a thriller character who discovers he doesn't know whom to trust, cybersecurity experts start running through the options. Can we recognize malware by its identifying characteristics? No, because each piece of malware can be different, and it can keep changing its appearance. Can we recognize it by the tools it needs to spread? No, because the malware might be a payload inserted by someone or something else.

Can we find malware by looking in likely hiding places? No, because it could be in a hiding place we didn't know was there—an area of memory we can't see or some component we didn't even realize had a memory. It could be moving around even as we're looking for it. It could copy itself into the place we just looked and erase itself from the place we're about to look.

Can we create a safe area, bit by bit, reading every line of code in each program to make sure it's innocent? The problem is that we can look directly at a line of malware and not recognize it. Sometimes a tiny modification in a line of code can cause a malicious effect. Malware doesn't need to be in the individual lines of code. The malicious part of the malware might be the sequence of operations that causes a normal instruction to be carried out at exactly the wrong time.

If all else fails, can we recognize malware by what it does? This won't work either. Malware can take control of every display, message box, graphic or reading. It can make sure you see only what it wants you to see. If you do manage to catch it doing something bad, it might be too late. If the first time a malicious program operates it turns your missiles back at you, fries your electric generators or blows up your refineries, it won't do much good to recognize it by that behavior.

We truly can't trust anything. The very computers we are using to search for malware might be the vehicles delivering it. Our authentication systems could be authenticating programs infected with malware. Our encryption systems could be encrypting malware. Even if we manage to come up with an effective barrier, we will not know which side the malware is on.

This is the world many cybersecurity professionals are currently living in. We are stopping most malware, most of the time. But we don't have a reliable solution for the cases where it might matter most. America and its allies have always been good at coming up with timely breakthroughs when they are most needed. We need one now. SA

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Accelerating Software Modernization with Artificial Intelligence

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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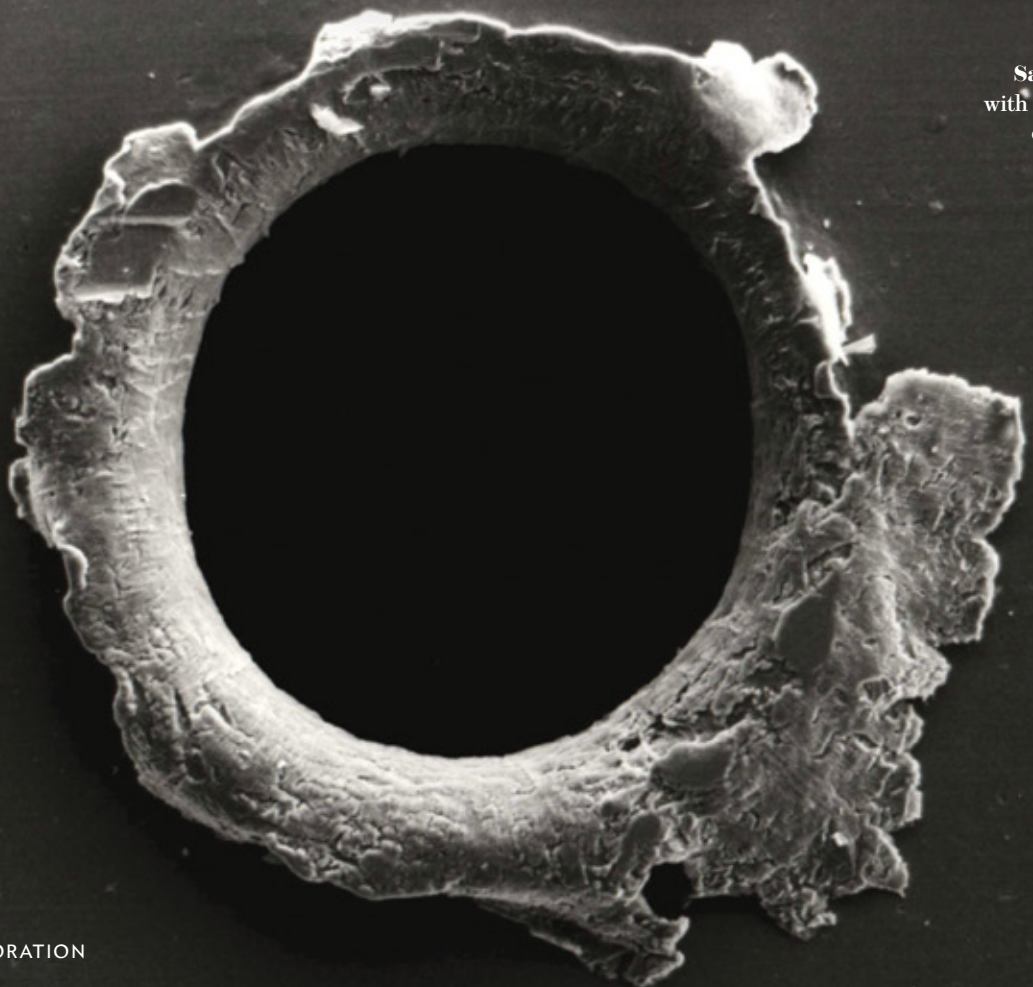

Satellite panel with damage from orbital debris

SPACE EXPLORATION

On the Trail of Space Trash

The U.S. Air Force has a new plan to track tiny pieces of orbiting debris

Since the space age began, the orbital realm has become increasingly littered with the detritus of skyward human striving—spent rocket boosters, dead satellites, stray pieces of hardware. Debris is piling up with such speed that it has become a threat to the kind of spacefaring endeavors that spawned it in the first place.

A September report by the National Research Council found that the debris field is so dense that collisions between objects in orbit will create additional debris faster than space junk falls out of orbit. The predicted outcome: an exponential growth of the number of pieces of space debris.

Already millions of pieces of refuse five millimeters and up circle Earth in a high-velocity swarm, each packing enough kinetic energy to disable a satellite. Far more sobering is the threat to human life. In June the six astronauts onboard the International Space Station took shelter in escape capsules when a piece of debris came within a few hundred meters of the station.

The U.S. is now taking preliminary steps to manage the threat of space junk by implementing better tracking systems. Space Fence, a new $6-billion radar system that the U.S. Air Force is planning, could dramatically increase the number of orbital objects under surveillance after it comes online around 2017.

As planned, Space Fence would comprise two radar stations in the Southern Hemisphere, which will take over for a 1960s-era radar system. Whereas the present system operates in the VHF band, Space Fence will use shorter-wavelength S-band radar, which affords better resolution for tracking debris. "The smaller the wavelength, the smaller the objects," says Scott Spence, director of Raytheon's Space Fence program. Raytheon and Lockheed Martin are vying for the government contract. The current debris catalogue goes down to roughly softball-size objects, but Space Fence, Spence says, may be able to track objects as small as a marble at lower altitudes.

Space Fence and other smaller-scale projects aim to increase what the military calls "space situational awareness." How that awareness might progress to remedial action—the removal of orbital debris—remains unclear, though. *—John Matson*

COURTESY OF NASA ORBITAL DEBRIS PROGRAM OFFICE

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DO THE MATH

Bigger Plates, More Food—Or Is It the Other Way Around?

When the same set of data yields opposite conclusions

A recent study by researchers at the University of Utah suggested that the amount of food diners in a restaurant consumed was influenced by fork size. I haven't seen details of the study, but it does remind me that people can draw diametrically opposite conclusions from the same raw data by altering definitions ever so slightly.

If only such contradictory results were contrived and isolated phenomena, but they're not. When dealing with weakly correlated quantities, we often can come up with spurious trends and associations by artfully defining the size of the categories we use. This has been done recently in studies of violent crime to show that certain categories of crime were changing in the desired direction, and I intend to illustrate the point here with a similar story.

Using the fork study for inspiration only, let's see how small variations in definitions can make all the difference. Imagine 10 diners at a buffet and consider the possible influence of plate size on how much they consume. Three diners were provided with plates that were deemed small, say, less than 8 inches in diameter, and they consumed 9, 11 and 10 ounces of food, for an average of 10 ounces. Now further assume that four diners were provided with medium-size plates, say, between 8 and 11 inches in diameter, and they consumed 18, 7, 15 and 4 ounces of food, for an average of 11 ounces.

Finally, we'll assume that the remaining three diners were provided with plates deemed large, say, larger than 11 inches in diameter, and they consumed 13, 11 and 12 ounces, for an average of 12 ounces.

Spot the trend? As the plate sizes increased from small to medium to large, the average amount consumed increased from 10 to 11 to 12 ounces. Aha, a nice result!

But wait. What if the medium-size plates were very slightly redefined to be between 8.2 and 10.8 inches, and the small and large plates were redefined accordingly? And what if this redefinition resulted in the misclassification of two diners? The diner who ate 18 ounces of food was actually provided with a small plate (say, 8.1 inches in diameter), and the diner who ate only 4 ounces was actually provided with a large plate (say, 10.9 inches in diameter).

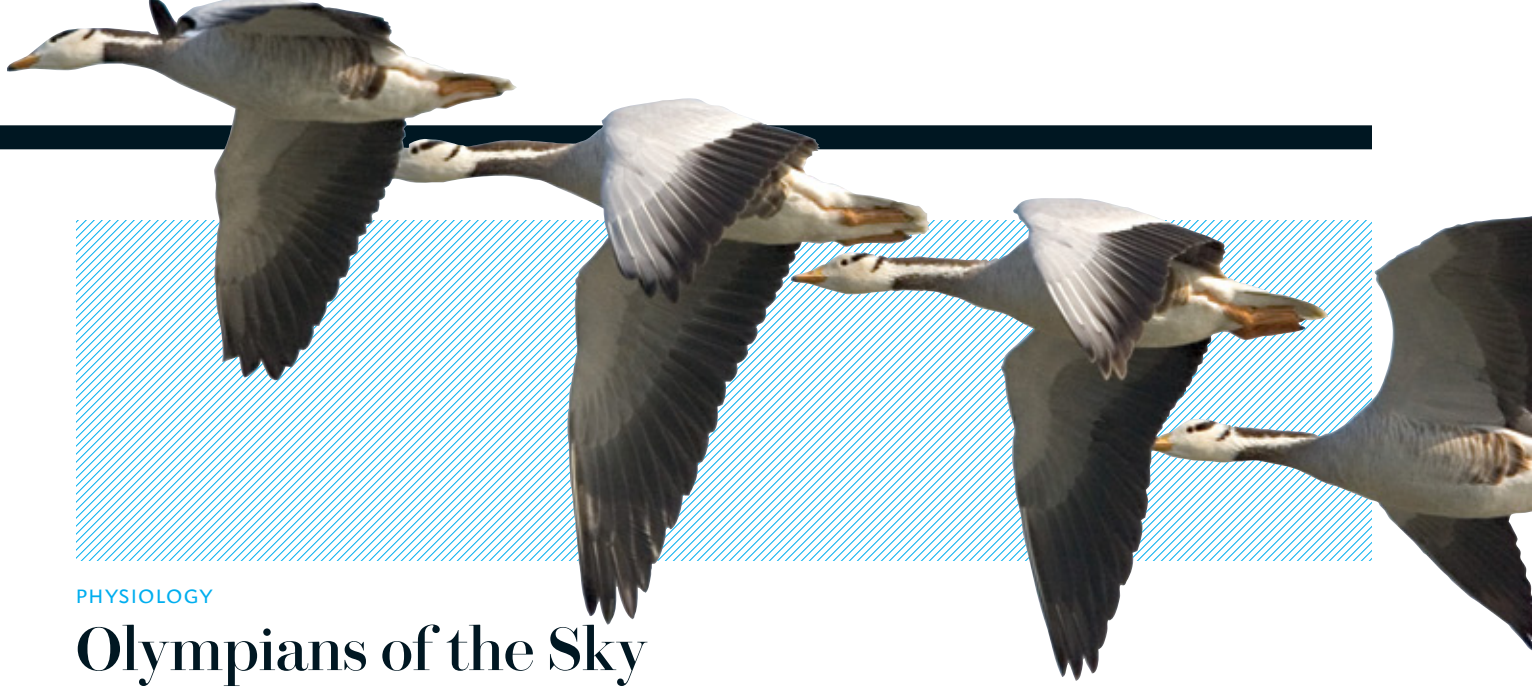
Let's do the numbers once again under this assumption. Four (rather than three) diners were provided with small plates, and they consumed 9, 11, 10 and 18 ounces of food, for an average of 12 ounces. Two (rather than four) diners were provided with medium-size plates, and they consumed 7 and 15 ounces of food, for an average of 11 ounces. Four (rather than two) were provided with large plates, and they consumed 4, 13, 11 and 12 ounces of food, for an average of 10 ounces.

Spot the trend? As the plate sizes increased from small to medium to large, the average amount consumed decreased from 12 to 11 to 10 ounces. Aha, a nice result!

Moreover, small samples are not the problem here. A large number of data points make this sleight of hand even easier because it provides more opportunity to fiddle with the categories. Anyone for sunspot intensity or Super Bowl outcomes? —*John Allen Paulos*

Paulos is professor of mathematics at Temple University (www.math.temple.edu/paulos).

RYAN McVAY Getty Images



PHYSIOLOGY

Olympians of the Sky

Researchers unravel some long-standing mysteries of bar-headed geese, the world's highest-flying birds

Climbers struggling the last few steps to the peak of Makalu in the Himalayas have long marveled at the sight of bar-headed geese flying high above to their winter refuge in India. The birds cruise at an altitude of 29,500 feet, nearly as high as commercial aircraft.

For years scientists believed that strong tailwinds and updrafts aided the geese on their journey. A team of researchers led by Charles Bishop of Bangor University in North Wales tested this theory by tracking more than a dozen bar-headed geese harnessed with small backpacks containing satellite transmitters that established their location, speed and altitude.

To their surprise, the researchers discovered that instead of flying in the early afternoon, when heat from the earth can create 12-mile-per-hour updrafts, bar-headed geese consistently fly at night or during early-morning hours, when there is actually a slight downdraft. In a paper published recently in the *Proceedings of the National Academy of Sciences USA,* the team theorizes that because air is cooler and denser at these times, it allows the geese to generate greater lift. Cooler air also helps to regulate body heat and contains more oxygen, enabling geese to fly even as the air thins at higher levels.

Bishop and his colleagues also were amazed to find that the geese cross the Himalayas in a single day, traveling 20,000 feet in seven to eight hours. To fly so far at such a great height, the bar-headed geese must sustain a 10- to 20-fold increase in oxygen consumption. By comparison, lower-altitude birds such as the Canada goose cannot sustain *resting* levels of metabolism at 30,000 feet. Bigger wings, bigger lungs, a dense network of capillaries surrounding the flight muscle, and hemoglobin that more tightly binds oxygen to the lungs work together to sustain oxygen flow throughout the bird's circulatory system, including its flight muscle. Improving the understanding of why tissues in bar-headed geese are so adept at taking up oxygen might elucidate human respiration as well. *—David Godkin*

JOHN HOLMES *Minden Pictures*

ENTOMOLOGY

Zombie Insects

A bug expert discusses a sinister virus that causes gypsy moth caterpillars to self-destruct

You recently identified a gene known as* egt *that allows a specific group of viruses to control the behavior of caterpillars. Tell me what it does.
Gypsy moth caterpillars have a normal behavior they do every day. They climb out onto the leaves to feed at night. During the day they climb back onto the branches or bark to hide from predators because they're very obvious when they're on the leaves. But once caterpillars are infected with these viruses, known as baculoviruses, their levels of the EGT protein become elevated. Once that happens, you find them on leaves in the middle of the day. It's like: "What are you doing here?"

And how does that harm the caterpillars?
Eventually they climb to the tops of trees, where they get converted into a sac of virus that liquefies and rains virus particles down on the foliage below so that new hosts can be infected by eating the virus on the leaves. *Egt* is manipulating the insect to die in the right location to transmit the virus to new hosts.

What is the mechanism by which the gene does that?
In short, we don't know, but we have a couple of ideas. It was already known that *egt* blocks molting in caterpillars. What happens when the insects molt is they stop feeding for quite some time; if they're kept from molting, they're kept in a feeding state. It's possible that because they're being stimulated to keep feeding, they're staying up in the tree when everybody else is climbing down.

PROFILE

NAME
Kelli Hoover

TITLE
Professor of entomology, Pennsylvania State University

LOCATION
University Park, Pa.

What are some other viruses that can change host behavior?
If you think about rabies, rabies causes the infected animals to come out during the day when they're normally nocturnal, and their behavior becomes more aggressive. There's also a really cool virus that is sexually transmitted in moths. It causes the female moth to keep calling for mates by sending out pheromones, even though she already just mated. That way she infects more and more males. Finally, in toxoplasmosis, cats are the primary host, but mice get infected. When mice are infected, they lose their fear of cats, and they're more likely to get eaten, which allows the pathogen to be transmitted to cats.

What does this mean for humans?
It certainly does suggest that other pathogens may contain genes that influence behavior, even in humans. When you have the flu, you cough a lot, which can help transmit the virus to other people. Is that a symptom, or is it the virus making us do that? And has that been selected for through evolution? Who knows? —*Anna Kuchment*

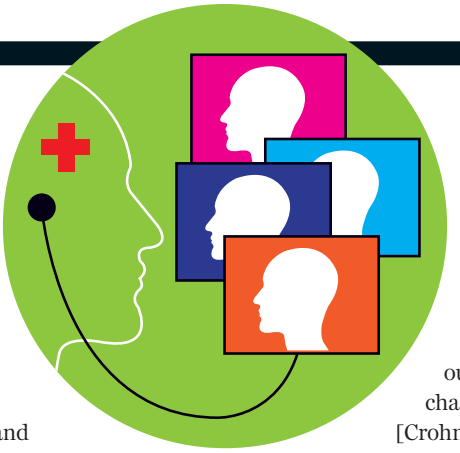
Gypsy moth caterpillar

ALAMY

HEALTH

Social Medicine

A new Facebook-like Web portal turns doctors and patients into research collaborators



Despite medical advances, the treatment of many chronic diseases remains haphazard and inconsistent. Teenagers with Crohn's disease, a painful digestive disorder often diagnosed in adolescence, for example, sometimes get conflicting information regarding medications, diet modifications and alternative therapies. To help improve the care these patients receive, a team of pediatricians and computer scientists is developing a new type of social network that turns doctors and patients into research collaborators.

Here is how it works: With each therapy or treatment modification, doctor and patient participate in a mini clinical trial. The patient records symptoms through daily reports, filed via text message or the Internet. The doctor uses that information to make immediate decisions. Should the dosage of medication be changed? Is the new diet helping to alleviate symptoms? And the data from those individual experiments are then deposited in a Web bank, where they can be aggregated with other patient data, from similar experiments, to further the understanding of the condition in question. In early tests of this process, doctors were able to increase the rate of remission from 55 to 78 percent without adding any new medications to their arsenal. "The idea is to make care continuous and to collect real-time data that will change our understanding and treatment of [Crohn's]," says Peter Margolis of Cincinnati Children's Hospital Medical Center, a co-founder of the new portal, the Collaborative Chronic Care Network.

The network, known as C3N, launched earlier this year at some 30 institutions around the country. For now it focuses on pediatric Crohn's, but it could grow to include other conditions, such as diabetes, heart disease, psoriasis and some cancers. The site's founders believe C3N will also provide a new platform for clinical research, one that is significantly less profit-driven. "Because large-scale clinical trials are so expensive, we only ever really test the treatments that promise a big payoff," says Ian Eslick, a Ph.D. candidate at the M.I.T. Media Lab and C3N's chief Web architect. "With C3N, we can scientifically test all the other things—probiotics, gluten-free diets, changes in iron intake—that people are already trying at home and that seem promising, even if they aren't profitable."

—Jeneen Interlandi

Illustrations by Thomas Fuchs

ENVIRONMENT

Halting Hurricanes

Tropical cyclones are nature's most powerful storms. Can they be stopped?

As another active hurricane season in the Atlantic winds down, some atmospheric scientists say they have the tools to stop or slow the powerful storms. Their efforts, however, are hampered by a lack of funding and tricky legal issues.

Until recently, the U.S. Department of Homeland Security has been investigating whether seeding storm clouds with pollution-size aerosols (particles suspended in gas) might help slow tropical cyclones. Computer models suggest that deploying aerosols can have "an appreciable impact on tropical cyclone intensity," writes William Cotton, an atmospheric scientist at Colorado State University. He and his colleagues recently reviewed such work in the *Journal of Weather Modification*. In fact, human pollution may already be weakening storms, including August's Hurricane Irene. "[Computer] models all predicted that the intensity of Irene would be much greater than it was," Cotton notes. "Was that because they did not include aerosol effects?"

Other would-be storm stoppers, including Microsoft billionaire Bill Gates, have focused on feeding cold water to the hot storms to slow their momentum. The Gates-backed plan proposes using a fleet of wave-powered rafts to spread a slick of colder ocean water pumped up from the depths in the path of an onrushing storm. The trouble with that process is that it could prove unwieldy. It would require hundreds of devices, and because storms are so difficult to track, placing them would be a challenge. The proof of concept will soon get a test of sorts in Hawaii. The U.S. Navy plans to deploy a prototype device that extracts energy from the temperature difference between surface and deep-ocean water. The device will involve pumping cool water to the ocean surface, in much the same manner as would be required to stop a typhoon.

Would dispelling storms with cold water be a good idea? Tropical cyclones, for all their destructive force, are one of the planet's ways of redistributing heat from the tropics to the poles. Shutting that down might have unforeseen consequences, and shifting a storm's course could spawn punitive action from people in the new path, as a team of engineers, public policy experts and atmospheric scientists wrote in *Environmental Science and Technology* in April.

Regardless, for all their power, tropical cyclones are sensitive. To exploit that sensitivity, scientists would need accurate information on a storm's future course, says meteorologist Ross Hoffman of Atmospheric and Environmental Research. But the U.S. government is cutting funding for the satellites that make such tracking and prediction possible. For now flood maps and evacuation plans remain our best protection.

—David Biello

SUSPECT SCIENCE

"Little girls who have a negative reaction to this potentially dangerous drug don't get a … do-over."

—Republican presidential candidate Michele Bachmann overstating the risks from a vaccine against human papillomavirus.

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

COURTESY OF NASA GODDARD MODIS RAPID RESPONSE TEAM (*hurricane*); STEVE POPE *Getty Images* (*Bachmann*)

ecology loves economy

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ANTHROPOLOGY

Meet Your Newest Ancestor

A fossil of a shrewlike creature pushes back by 35 million years the day when mammals first nourished their young in the womb

Most humans think of the placenta as something that gets tossed out after childbirth. In fact, its appearance millions of years ago was a significant evolutionary development that gave rise to the vast majority of mammals alive today, from bats to whales to humans.

Until now, scientists believed that placental mammals first appeared some 125 million years ago. At that point, they branched off from the lineage that developed into modern marsupials, which nourish their young in their pouches instead of through placentas. Yet a recent fossil find backdates that divergence by about 35 million years, showing that mammals with placentas, known as eutherians, shared the earth with dinosaurs much longer than previously thought.

The fossil, described in August in the journal *Nature* (*Scientific American* is part of Nature Publishing Group), belongs to a tiny, shrewlike creature known as *Juramaia sinensis* that roamed China 160 million years ago. It appears to be the oldest known ancestor of placental mammals, according to a research group led by Zhe-Xi Luo, a paleontologist at the Carnegie Museum of Natural History.

Placental nourishment allows a more rapid and efficient transfer of nutrients from mother to offspring, which can result in faster brain development, larger mature brains and increased metabolic rate—all of which have had broad implications for the evolution of the behavioral and social complexity observed among today's mammals.

The *Juramaia* fossil also yields important clues about the life of early eutherians. This animal appears to have been an insectivore, judging from the shape of its teeth, and it had robust forelimbs, which could have helped it to climb trees. This ability may have enabled it to take over as yet unexploited territory for both safety from predators and access to insects among the foliage. Any opportunity to reduce competition with other Jurassic mammals by staking out higher ground may have helped strengthen *Juramaia*'s divergence from marsupials, leading it to become the ancestor of an extremely diverse group of animals.

The discovery of this fossil corroborates previous molecular studies, which estimated the divergence between eutherians and other mammals to have occurred around 160 million years ago—yet such estimations are often taken with a grain of salt until they are bolstered by hard physical evidence in the form of fossils. This is a prime example of the way in which multiple lines of scientific investigation can work together to draw robust conclusions and make well-supported hypotheses, thereby highlighting the value of integrative approaches to answering scientific questions. —*Anne-Marie Hodge*

MARK A. KLINGLER *Carnegie Museum of Natural History (Juramaia);* KEVORK DJANSEZIAN *Getty Images (Perry)*

SUSPECT SCIENCE

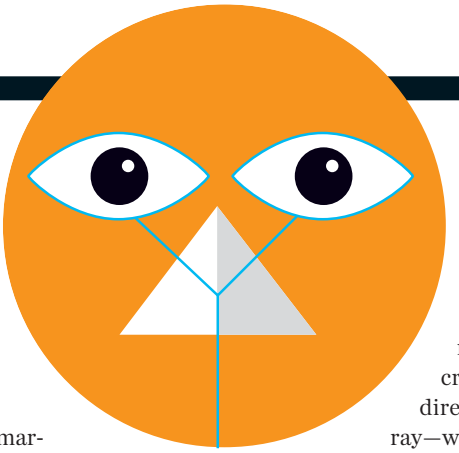
"The idea that we would put Americans' economy at jeopardy based on scientific theory that's not settled yet, to me, is nonsense."

—Governor Rick Perry of Texas discussing climate change at a recent debate for Republican presidential candidates.

TECHNOLOGY

3-D, Hold the Glasses

A breakthrough may lead to more widespread adoption of 3-D TVs



Three-dimensional television got a major marketing push nearly two years ago from the consumer electronics and entertainment industries, yet the technology has one major limitation: viewers need special eyeglasses to experience the 3-D effect. Now the marketing experts say that the technology will never catch on in a big way unless viewers can toss the glasses entirely.

Although 3-D technology sans specs is available for small screens on smartphones and portable gaming devices, these devices use backlit LCDs, which can be a big battery drain and limits how small the gadgets can be made. More recently, researchers have begun to use light-emitting diodes, which show more promise. They are developing autostereoscopic 3-D using tiny prisms that would render 3-D images without glasses. Because these LEDs get their lighting from organic compounds that glow in response to electric current, they can be thinner, lighter and more flexible than LCDs. The innovation is detailed in the August issue of the journal *Nature Communications.*

The researchers—from Seoul National University, Act Company and Minuta Technology—used an array of microscale prisms placed on a screen to create a filter that guides the light in one direction or another. Using such a prism array—which the researchers refer to as a Lucius prism after the Latin name meaning "shining and bright"—they were able to display an object on the screen that could be seen only when viewed from a particular angle. By manipulating the intensity of light, the scientists could show from the same screen two distinctly different images—one to a viewer's left eye and a second to the right eye. Seeing the two images together creates a sense of depth that the brain perceives as 3-D—all without the help of special lenses.

Some researchers have reported success with other approaches to glasses-free 3-D. The HTC EVO 3D and LG Optimus 3D smartphones, for example, feature parallax barrier screens made with precision slits that allow each eye to see a different set of pixels. Unfortunately, this approach requires the viewer to look at the screen at a very specific angle to experience the 3-D effect, a drawback that this new technique may be able to overcome. *—Larry Greenemeier*

Best of the Blogs

Starting this month, Advances features edited highlights from SA's blog network (see blogs.ScientificAmerican.com), where journalists and scientists write on subjects as diverse as ant behavior, astrophysics, education, human reproduction, urban anthropology, and the intersection of art and science.

BEHAVIOR

Of Flash Mobs and Four Loko

An out-of-context experience can feel more intense

On an ordinary afternoon at Copenhagen Central Station, a performer sets up a drum in the center of a large hall. A cellist joins him. A woman approaches with her flute. They strike up a melody that seems familiar. A clarinet and bassoon and other instruments start playing. People pull out their cell phones and record video. Within minutes an entire symphony orchestra has assembled in the middle of the station, and suddenly it's clear that this isn't just your typical street performance; it's the Copenhagen Philharmonic, and the tune is Ravel's *Boléro.* This musical flash mob is a very different experience from watching an orchestra perform in a music hall, perhaps because of the novelty of the surroundings.

The same sort of disconnect may explain the peculiar potency of Four Loko, a fruit-flavored, caffeinated, alcoholic drink that was invented by three Ohio State University students in 2005. Following a series of reported hospitalizations, in 2010 the Food and Drug Administration declared that it was illegal to add caffeine to alcoholic beverages, and the makers of Four Loko complied.

Case closed? That caffeinated alcoholic drinks are dangerous is clear, but is caffeine the culprit? Shepard Siegel, a psychologist at McMaster University in Ontario writing in a recent issue of *Perspectives on Psychological Science,* doesn't think so.

For one thing, caffeine doesn't seem to affect the way that alcohol gets absorbed by the body. Moreover, many drugs, including alcohol, are known to be more potent if they are taken in an unusual context. In a 1976 paper in *Science,* Siegel termed this the "situational specificity of tolerance." Environmental variables ranging from the room where a drug is administered to flavor cues can influence an individual's drug-related tolerance. What this comes down to is classical Pavlovian conditioning. The body of a social drinker learns to prepare for the alcohol in response to the environment, before the alcohol is even ingested. Siegel's argument is that people became especially drunk after drinking Four Loko because of the unexpected way in which it was presented: it doesn't actually taste like alcohol.

If Siegel is right, the decaf approach that the manufacturer of Four Loko has now taken could be troubling. It has announced a new beverage that comes with "a brand new flavor profile every four months." This doesn't fix the problem. Once someone becomes tolerant to the effects of the alcohol in one flavor, his or her tolerance would be eliminated when the next one is released. Intentional or not, Four Loko takes advantage of the situational specificity of tolerance. It has more in common with the Copenhagen Philharmonic flash mob than with your morning cuppa joe. —*Jason G. Goldman*

NEUROSCIENCE

Instant Recall

How many memories do we create in a day?

The series* Too Hard for Science?** ***discusses ideas scientists would love to explore that they think are difficult or impossible to investigate.

THE SCIENTIST: **Robert Stickgold, director of the Center for Sleep and Cognition at Harvard Medical School.**

THE IDEA: How many memories does a person create in one day? Assumptions regarding this number are at the foundation of many studies of the brain. One could put recording equipment on volunteers and compare what they experienced to what they actually remembered about events, Stickgold suggests. This is something he and his colleagues attempted.

THE PROBLEM: One difficulty regards how one counts memories. Is going to the grocery store one memory or a series? Remembrances are fractal in nature: the deeper a person looks into one memory, the more details one can unearth.

Furthermore, Stickgold adds, "There probably really isn't anything in the brain that's a discrete memory." The brain is one vast, interconnected network, so how much you glom together and call a memory—"Well, it's not a question that's meaningful at the level of the brain." —*Charles Q. Choi*

JOE RAEDLE *Getty Images*

ERIK OVERCAME THE CHALLENGES OF MOUNT EVEREST, BUT HE NEEDS YOUR HELP TO OVERCOME BLINDNESS.

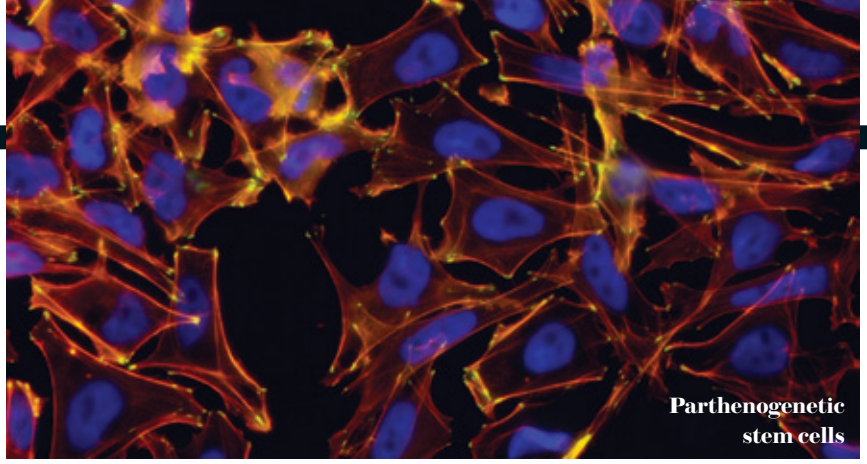
Erik Weihenmayer is the only blind person in history to climb Mount Everest. He lost his vision to a retinal disease called retinoschisis. Currently, there is no cure for his condition. The Foundation Fighting Blindness is funding critical research to find treatments and cures that could one day restore vision lost to retinal diseases. Though Erik may never see again, he supports the work of the Foundation so that others affected by retinal disease have a brighter future.

Foundation Fighting Blindness®

A CURE IS IN SIGHT.

You can help. To learn more and for free retinal disease information, call 800-683-5555 or visit FightBlindness.org

Erik Weihenmayer is a proud spokesperson for the Foundation Fighting Blindness.



Parthenogenetic stem cells

FROM "DERIVATION OF HIGH-PURITY DEFINITIVE ENDODERM FROM HUMAN PARTHENOGENETIC STEM CELLS USING AN IN VITRO ANALOG OF THE PRIMITIVE STREAK," BY NIKOLAY TUROVETS ET AL., IN *CELL TRANSPLANTATION*, VOL. 20, NO. 6, JUNE 2011

BIOLOGICAL ENGINEERING

You Say Embryo, I Say Parthenote

Stem cells from unfertilized eggs may be too tightly regulated

U.S. stem cell scientists breathed a sigh of relief this July when a federal judge upheld the Obama administration's expansion of stem cell research. He ruled that work on existing embryonic stem cell lines derived outside federally funded labs did not violate a ban on the destruction of embryos. Despite the legal victory, however, many investigators remain frustrated that a newer method for creating stem cells remains off-limits for funding.

Human embryonic stem cells typically come from fertilized eggs. In 2007, however, scientists at International Stem Cell, a California-based biotech firm, reported the first successful creation of human stem cell lines from unfertilized eggs. They used a process called parthenogenesis, in which researchers use chemicals to induce the egg to begin developing as if it had been fertilized. The egg—called a parthenote—behaves just like an embryo in the early stages of division. Because it contains no genetic material from a father, however, it cannot develop into a viable fetus.

Just like embryonic stem cells, parthenogenetic stem cells can be coaxed to grow into different kinds of human cells or tissue, ready to be transplanted into diseased areas of the body. International Stem Cell scientists have converted them into liver cells and plan to convert them into neurons for treating Parkinson's disease, pancreatic cells for diabetes, and other tissues. Meanwhile teams at the Massachusetts-based Bedford Stem Cell Research Foundation are working to improve the efficiency of methods of deriving stem cells from parthenotes.

Proving that unfertilized eggs will produce stable tissues in humans remains an obstacle, says Alan Trounson, president of the California Institute for Regenerative Medicine. "We need to see this done in other laboratories," he points out. That won't be easy. Guidelines from the National Institutes of Health and federal laws define parthenotes as embryos, which means that deriving new parthenogenetic stem cell lines is off-limits to all labs receiving federal funding—which is nearly all of them. Barring an unlikely turnabout, it will be up to a handful of private firms in the U.S. to carry the young field forward.

—Julia Galef

ECONOMICS

Low Taxes, High Rhetoric

What consumers really do with their tax cuts

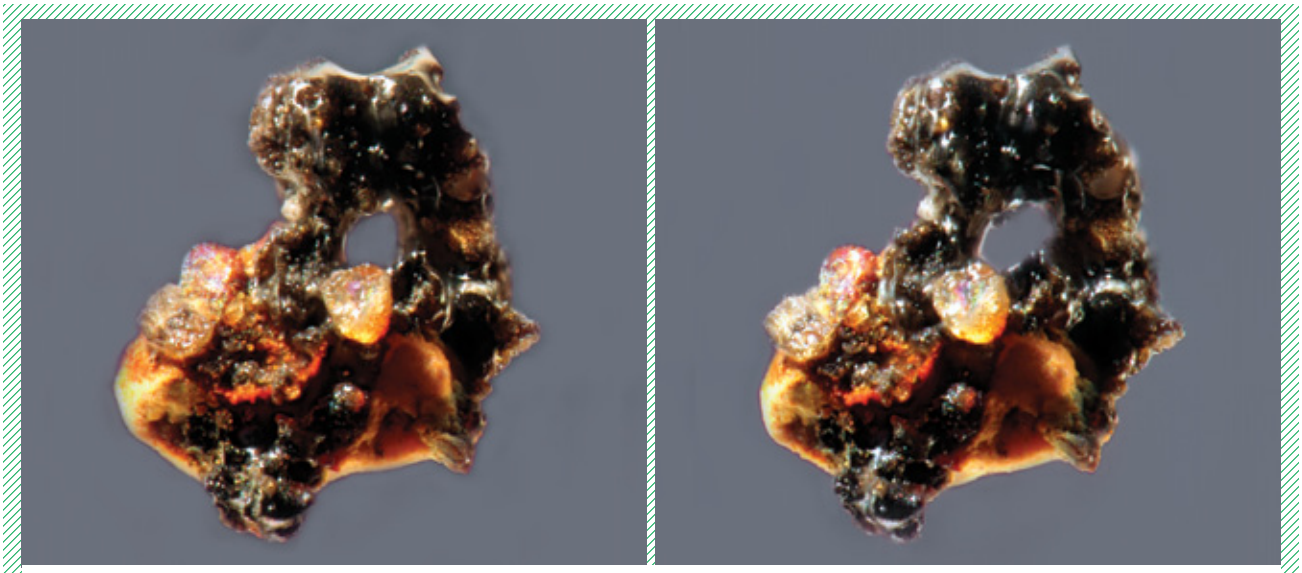
The Republican-Democratic debate over income tax rates and the size of government has been long on rhetoric but short on data. What does published research say about what different economic groups do with savings from income-tax cuts? Will the economy slow if Washington cancels tax cuts on millionaires and billionaires?

Most experts agree that tax cuts can stimulate a weak economy over the short term through increased consumption and investment, provided the money flows to people who are more likely to spend than save. Past observation has shown that because lower-income people often live paycheck to paycheck, they are more likely than the wealthy to spend. Yet "our research suggests that hasn't been true for the past decade," says economist Joel Slemrod of the University of Michigan at Ann Arbor. Because the last few tax cuts have followed financial crises, poorer people may have used the extra income to increase their cushion by building up assets or paying down debt. But the rich haven't been spending freely either. Last year a study by Moody's Analytics suggested that the 2001 and 2003 tax cuts spurred the wealthy to significantly increase their savings as well.

What should the administration do to design a better economic shot in the arm? One finding on which researchers seem to agree is that consumers respond more vigorously to policies thought to be long-lasting. Therefore, Slemrod says, one farsighted action may plausibly help the economy: convincing the general public that the federal government is committed to getting its fiscal house in order.

—Bryn Nelson

COMMENT AT ScientificAmerican.com/nov2011



COURTESY OF GARY GREENBERG www.sandgrains.com

WHAT IS IT?

Moon grain: Researchers are using recent advances in imaging to reexamine lunar samples from *Apollo 11*. Gary Greenberg, a research affiliate at the University of Hawaii Institute for Astronomy, took this 3-D stereo image (cross your eyes slightly until there are three images, then focus on the center) of a single grain of moon sand (magnified here about 300 times). It reveals a ring created by a micrometeorite that struck it. The impact resulted in melting, and as the particle quickly cooled, it created a glassy structure. Greenberg and his colleagues hope viewing these grains in greater detail may help scientists learn more about the moon's evolution.

—Ann Chin

Francie Diep is working toward a master's degree in science journalism from New York University.

Cholesterol Conundrum

Changing HDL and LDL levels does not always alter heart disease or stroke risk

Most people who are even a little bit concerned about their cholesterol know that there is a "good" kind—known as HDL—and a "bad" kind—known as LDL. Research has shown that the higher the amount of HDL and the lower the amount of LDL in the blood, the less likely a person is to suffer a heart attack or stroke. As for the one in six Americans with unhealthy cholesterol levels, well, they can always hope to change their luck with a cholesterol-changing medication or two. Or can they?

Two major clinical trials in the past three years have greatly complicated the picture for these and perhaps other folks. The first study, from 2008, shows that lowering LDL levels does not always decrease the risk of having a heart attack. Similarly, results from the second study, released in the spring of this year, show that raising HDL levels does not always translate into fewer heart attacks or strokes.

These perplexing findings do not mean that people should stop taking their cholesterol drugs. The results have, however, underscored the danger of indulging in a common logical shortcut in medical thinking—assuming that artificially producing normal test results in a patient is the same as conferring good health on that patient. For one thing, drugs typically do not mimic normal conditions perfectly. For another, heart attacks and strokes occur after a complex series of processes that may take years to unfold. Simply altering one of these processes does not necessarily fix the whole problem.

GOOD VS. BAD CHOLESTEROL

Still, researchers and physicians, knowing the roles of LDL and HDL in the body, had good reasons to suspect that manipulating the levels could protect against heart attacks and strokes. Despite its bad reputation as a clogger of arteries, the cholesterol molecule is an irreplaceable component of many key parts of the body, from cell membranes to sex hormones. Indeed, this fatty, waxy substance is so important to life that evolution has produced several different mechanisms for transporting it through the bloodstream. Just as oil and water do not mix, neither do waxy cholesterol and watery blood, so cholesterol needs a kind of protective vehicle to surround it and carry it around the body. Two of the most important vehicles for the job are LDL (low-density lipoprotein), which delivers cholesterol to the various cells of the body, including the walls of arteries, and HDL (high-density lipoprotein), which removes cholesterol from the blood. HDL may also act as an antioxidant that reduces unhealthy inflammation in the arteries.

Danger: High LDL levels can lead to blockages of arteries that nourish the brain (*as in this angiogram*), heart and other organs.

GILLES PODEVINS *Corbis*

The trouble begins when too much LDL-carried cholesterol winds up in the arterial lining and contributes to the buildup of fatty material, or atherosclerotic plaque. Much of the time the plaque stabilizes without creating too many immediate problems, but sometimes it bursts, triggering blood clots that lead to heart attacks and strokes if the clots prevent blood from delivering critical oxygen to heart or brain tissue. Without oxygen, the affected tissue dies.

People with high LDL levels may form arterial plaques that are more likely to burst. Some people develop extremely high LDL levels because of a genetic disease called familial hypercholesterolemia that severely limits their ability to clear cholesterol from their blood. They suffer heart attacks in their thirties or forties, which is several decades earlier than the average for the general population. On the positive side, those who maintain normal cholesterol levels (LDL less than 100 milligrams per deciliter of blood and HDL cholesterol levels greater than 40 mg/dL)

Malaysia Healthcare, a hidden jewel

> *"There is no doubt Malaysia is fast gaining recognition as a preferred destination for healthcare travelers with its highly skilled medical professional and personnel, state of the art medical equipment, modern facilities and infrastructure."*
> *Najib Razak, Prime Minister of Malaysia*

When I talk about Malaysia to my friends in Europe and the United States most of them are not even sure of its geographical location. Somewhere in South East Asia maybe? Some may think that it could be an Islamic state with the majority of the population living in the jungles. That is so far from the truth....Malaysia's capital, Kuala Lumpur is a world class city, with first world infrastructure and some of the best connectivity around. Just to arrive at hassle - free KLIA International airport is a pleasure in itself. It is only after dispelling the myths and misperceptions that one can talk about Malaysia's excellent healthcare and world-class hospitals.

Like so many areas of public service such as education or judicial, the healthcare system in Malaysia is a legacy left behind by the British from the pre-independence era. During the early days of nationhood, patients traveled abroad for high-end medical treatment, to The United States and Great Britain. With an increasing demand to establish their own specialty departments, many Malaysian doctors were sent overseas for training. Upon return their expertise was quickly put to the test in treating complex cases as well as in the training of a younger set of doctors and establish a competent healthcare team.

Today Malaysia has a well developed private and public healthcare system which serves the entire population as well as a growing international clientele seeking quality healthcare at affordable prices.

Perhaps no one person in Malaysia embodies the growth and dynamism in the sector more than Datin Paduka Siti Sa'diah Sheik Bakir, managing director of KPJ Hospitals, the largest healthcare provider in the country with 22 hospitals and growing. Overseeing a business of this size would be a colossal feat, but under her management, KPJ has seen steady growth since its inception over three decades ago.

MalaYsia HEALTHCARE
Quality care for your peace of mind

Her personality and youthful charm as well as an endless supply of energy have made KPJ into what it is today; a market leader as well as an award winning group of hospitals. Just recently Datin Paduka was awarded CEO of the year by American Express. She

Datin Paduka Siti Sa'diah Sheik Bakir, receiving leadership award from the Prime Minister

presides over the most successful stock on the Malaysian bourse and received the award for its 1 Billion Ringgit turnover.

When asked what she thought Malaysia's main attributes were when it comes to becoming a premier health tourism destination, she responded with: "affordable procedures particularly if you are coming from a Western country such as the United States, where a triple bypass could run as high as $100,000 US Dollars. In Malaysia that procedure would be closer to $25,000 US Dollars. Secondly, modern facilities, where extensive investment has been made to ensure that all medical centers are equipped with state-of-the-art facilities - that is the norm. Additionally there is a genuine professional medical staff with internationally-recognized credentials at all major hospitals. Finally the high level of English spoken throughout the country, coupled with many exciting and varied tourism options, make Malaysia the country of choice."

Malaysia Healthcare Travel Council.

Medical tourism is the new buzzword in the tourism industry around the world as it helps in enhancing the revenue portfolio of various associated sectors. In Asia it is one of the fastest growing segments of the tourism industry. Asian countries like Malaysia have been pouring investments into their healthcare infrastructures to meet the demand for excellent, quality medical care through first class facilities and well trained medical staff.

In recognition of the growing medical tourism industry and its potential, Malaysia decided to do something about it and formed the Malaysia Healthcare Travel Council. MHTC was officially launched by the Prime Minister in 2009 with its main objective being to streamline service providers and industry players in both private and public sectors and thereby drive the industry to greater heights. According to its CEO Dr. Mary Wong Lai Lin, MHTC has been established to spearhead the development and promotion of medical travel or "healthcare tourism".

Dr. Mary's passion and commitment to the branding of Malaysia is evident in discussion. She firmly believes in the quality and proficiency that exists here in Malaysia and is committed to ensure that the outside world becomes aware through continuous brand building. Dr. Mary stated that "although Malaysia is emerging as one of the forerunners in health tourism, we still have a long way to go. We have a fast-growing private healthcare sector as well as large base in the public healthcare sector; we do hold the potential for future growth." In keeping with the global trend for countries to showcase their medical services, Malaysia shines like a hidden jewel. Not only is it extremely affordable, it has some of the best medical equipment in the world run by first class doctors. During recent familiarization tours of some of the private hospitals which she had organized for visitors from the USA and Canada, they came away awestruck by the facilities available here such as MRI scans and CT scans and other high end equipment.

Steady Growth

With respect to growth Dr. Mary went on to say that the healthcare sector will become the engine for growth. The sector can be transformed from a social service and consumer of wealth to a private sector driven engine of growth, all this under the Malaysian Government's Economic Transformation Program (ETP).

Dr. Mary Wong Lai Lin, CEO, MHTC

The growth has been phenomenal, according to a study by the Association of Private Hospitals Malaysia (APHM), the number of foreign patients at private hospitals increased from 296,687 in

2006 to 341,288 in 2007 and over half a million in 2008. APHM predicts an increase by 25% from 2009-2011.

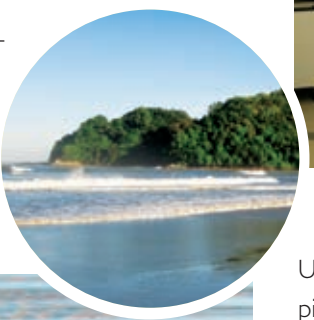
In recent years there has been a significant growth in the number of specialist hospitals and clinics offering a wide range of medical services including cancer treatment and pain management, cardiology and cardiothoracic surgery, fertility treatment, general screening and wellness, orthopedic surgery and reconstructive surgery to name a few.

KPJ's Ampang Puteri Hospital is one of two private hospitals to perform plastic surgery in line with the promotion of medical tourism. This accredited hospital is a few minutes from the Twin Towers city center area and is at the heart of embassy row. Its principal resident plastic surgeon, Dr. Abdul Jilil Jidon is one of the most sought after specialists in his field. He receives patients from around the world. According to Dr. Abdul "the cost of living here is reasonably low and procedures are cheaper than in neighboring Thailand or Singapore. Plastic surgery here is safe and affordable and one can have a relaxing vacation while recuperating."

Obesity is a growing problem worldwide and KPJ opened the Severe Obesity (Bariatric) Center at KPJ Damansara Specialist Hospital in Kuala Lumpur. Dr. Haron Ahmad is the consultant surgeon in advanced laparoscopic surgery and obesity. He works in close contact with Dr. Paul Wizman a renowned bariatric specialist who flies in to Kuala Lumpur several times a year to assist the team at KPJ.

Dr. Yahya Awang, is fondly known in Malaysia as "the man of the heart" and is KPJ's Consultant Cardiothoracic surgeon at Damansara Hospital in Kuala Lumpur. Yahya's claim to fame came in 1989 when he was leading the team of doctors that operated on the former Prime Minister Tun Dr. Mahathir. Dr. Yahya has been consulting at KPJ Damansara Specialist Hospital in Kuala Lumpur since 2004. Yahya is bullish on Malaysia's future in the medical sector stating that "now we have almost 50 cardiothoracic surgeons. When I first started there were only a handful."

Malaysia boasts several prominent World Heritage sites, most notable of which are Malacca and the island of Penang. Both places have excellent hospitals and are particularly well suited to international patients.



Ten reasons to make Malaysia a preferred travel destination:

1. Affordable
2. Modern facilities
3. Professionals with internationally recognized credentials
4. Short waiting times
5. Political stability
6. Ease of entry
7. Low cost of living
8. Excellent accommodation
9. Excellent infrastructure
10. Lots to see and do

Penang's Adventist Hospital is part of an international network of more than 500 hospitals and healthcare facilities operated by Adventist Health System and is associated with Loma Linda University in California and The Florida Hospital in Orlando. It is the first private hospital in northern Malaysia to perform micro vascular coronary bypass, laser heart surgery (TMR) and open heart surgery.

Dr. Abdul Jilil Jidon

The Mahkota Medical Centre in Malacca is actively involved in health tourism with large numbers of patients coming from Brunei and Indonesia. In 2008 the hospital achieved international recognition through winning the ASEAN Healthcare Excellence Award.

Clearly Malaysia has cutting edge medical innovations that give it a lead over other Asian nations. When it comes to imaging devices used in preventive healthcare to high tech treatment for the advanced stages of diseases, Malaysia has it all.

For more information refer to:
www.myhealthcare.gov.my
www.hospitals-malaysia.org

KPJ HEALTHCARE BERHAD (247079-M)
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www.kpjhealth.com.my

Care For Life

CELEBRATING 30 YEARS CARE FOR LIFE 1981 - 2011

QUALITY HEALTHCARE

Since our inception in 1981, KPJ Healthcare Berhad (KPJ) has cemented a reputation as one of the leading healthcare providers in the region with more than 20 specialist hospitals in Malaysia and 2 in Indonesia providing promotive, preventive and curative medical services. KPJ's education arm has been awarded a University College status in 2011.

OUR STRENGTHS

- Availability of more than 800 medical specialists as well as 8,000 supporting staff such as nursing, paramedic, pharmaceutical, technical and management services.
- Complementing the expertise of our specialists, our hospitals are equipped with modern medical technology as well as facilities that allow us to offer a comprehensive set of medical services including cardiac, orthopaedics, oncology, bariatric surgery, and reconstructive and plastic surgery, among others.
- Our commitment to patient safety is reflected in 10 KPJ hospitals being accredited by the Malaysian Society for Quality in Health (MSQH) which is affiliated with the International Society for Quality in Health Care (ISQua),while other hospitals are in the process of being accredited.
- KPJ hospitals also implement the Integrated Management System (IMS), thus guaranteeing high standards in quality services, environmental safety and health management.
- The abovementioned qualities have enabled KPJ hospitals to attract 2.2 million outpatients and 220,000 inpatients in 2010, including a sizeable amount of foreign patients from all over the world.
- The upgrading of KPJ's education arm to KPJ International University College of Nursing and Health Sciences (KPJIUC) in 2011, clearly signifies KPJ's efforts to continuously strive for excellence. This official upgrade is a testament to our unceasing commitment to excellence, and is a well-deserved recognition of KPJ's efforts in healthcare education.

AWARDS AND ACCOLADES OF KPJ HEALTHCARE BERHAD

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KPJ NETWORK OF HOSPITALS

MALAYSIA

ACCREDITED BY MALAYSIAN SOCIETY FOR QUALITY IN HEALTH (MSQH)

- KPJ Johor Specialist Hospital (JSH)
- KPJ Ipoh Specialist Hospital (ISH)
- KPJ Ampang Puteri Specialist Hospital (APSH)
- KPJ Damansara Specialist Hospital (DSH)
- KPJ Selangor Specialist Hospital (SgorSH)
- KPJ Seremban Specialist Hospital (SSH)
- KPJ Perdana Specialist Hospital (PdSH)
- KPJ Kajang Specialist Hospital (KjgSH)
- KPJ Penang Specialist Hospital (PngSH)
- Kedah Medical Centre (KMC)

MOVING TOWARDS ACCREDITATION

- KPJ Tawakkal Specialist Hospital (TSH)
- Puteri Specialist Hospital (PSH)
- Kuantan Specialist Hospital (KSH)
- Taiping Medical Centre (TMC)
- Damai Specialist Hospital (DmSH)
- Kuching Specialist Hospital (KcSH)
- Sentosa Medical Centre (Sentosa KL)
- Kluang Utama Specialist Hospital (KUSH)
- Sabah Medical Centre (SMC)
- Sibu Specialist Medical Centre (SSMC)

EDUCATION

KPJ International University College of Nursing and Health Sciences (KPJIUC)

- Main Campus (Nilai, N.Sembilan)
- Branch Campus (Johor Bahru, Johor)

throughout their life without medication are much less likely to suffer heart attacks or strokes.

A SHORTCUT IN LOGIC

With all this evidence linking cholesterol levels to heart disease risk, it is no wonder that researchers in general and pharmaceutical companies in particular reached a fairly straightforward, if simplistic, conclusion: anything—such as a medication—that reduces LDL levels and raises HDL levels must also reduce heart disease risk. By the 1980s the drug industry began marketing a whole family of cholesterol-lowering drugs called the statins, which work by blocking a liver enzyme that is essential for forming cholesterol. Clinical studies proved that statins do in fact reduce the number of heart attacks in people with high cholesterol. But is it the medications' cholesterol-lowering effect or some other aspect of how the drugs affect the body—such as its anti-inflammatory properties (inflammation is strongly suspected of contributing to atherosclerosis)—or even a combination of both that does the trick?

To some extent, as long as the statins were working, few people worried too much about why they were helping. But statins are not for everyone. Some people cannot tolerate the drugs' side effects, including muscle pain and, more rarely, liver damage. Others cannot lower their LDL levels enough simply by taking a statin. In addition, at least one in five people whose LDL levels are well controlled by their medications still experience heart attacks or strokes. "What are we going to do with these people?" asks Christie Ballantyne, chief of cardiovascular research at Baylor College of Medicine.

Thus, by the late 1990s the search was on to find drugs that could supplement the use of statins. One approach was to lower LDL levels using nonstatin drugs such as ezetimibe, which was approved by the U.S. Food and Drug Administration for its cholesterol-lowering ability in 2002. Studies had shown that ezetimibe reduces LDL levels in the body by a different molecular pathway than any that the statins use. Theoretically at least, the combination of a statin and ezetimibe should reduce LDL levels more than either alone. Another option was to raise HDL levels using a drug such as niacin, which is one of the B vitamins. Here again the idea was that a combination of drugs—one to lower LDL and one to raise HDL—should work better at reducing heart disease risk than any single medication.

Crucially, however, neither drug—ezetimibe or niacin—had yet been rigorously tested to see whether it actually reduced the number of heart attacks or strokes in a given population. That kind of investigation is more complicated and takes longer to conduct than does a test of how much LDL or HDL levels change in response to treatment. To determine if a drug actually reduces heart risk or stroke, researchers have to wait until enough study participants develop heart attacks or strokes to make a statistically valid comparison between those who took the trial drug and those who did not.

Clinicians were therefore eager to see the results of a 2008 study named ENHANCE, which compared a combination of ezetimibe and one particular statin drug, simvastatin, against simvastatin alone in people with familial hypercholesterolemia. To everyone's surprise, ENHANCE found no benefit from the combination treatment, at least with respect to the thickness of the trial participants' artery walls (thickened walls being a sign of advancing atherosclerosis and another potential indicator of heart disease). This result occurred despite the fact that the LDL levels of the combination therapy group dropped, on average, an extra 51 mg/dL.

Needless to say, the results generated more questions than answers. Did the ezetimibe produce a second effect that negated the beneficial effect of lowered levels of LDL? Or do statins trigger a beneficial anti-inflammatory effect that is the true reason for their benefit? Is LDL lowering as important as most people still think it is? The answers to such questions may become clear in 2013, when results are expected to be released of another study, which is specifically designed to determine whether an ezetimibe-statin combination works better than a statin alone in reducing heart attacks and strokes in test subjects. The clinical results for niacin, the HDL booster, looked more promising at first. A 2009 trial that compared adding either ezetimibe or niacin to standard statin treatment in people with heart disease found that niacin worked better than ezetimibe to reduce trial participants' artery thickness. Results from this study, combined with those of the ENHANCE trial, looked like bad news for ezetimibe and good news for niacin until this May, when the National Heart, Lung, and Blood Institute stopped its own clinical trial of niacin because researchers found no difference in the numbers of heart attacks and strokes suffered by trial participants taking niacin and a statin compared with participants taking a placebo and a statin.

A similar study, being run by the University of Oxford, is exploring whether niacin has an effect on heart disease or stroke cases in a broader selection of cardiac disease patients. Its results are expected in 2013.

LOOKING FORWARD

So far, then, only the statins have been shown to safely reduce the number of heart attacks and strokes in the average person with high cholesterol, and the reasons for their success are not fully understood. To Steven Nissen, who chairs the department of cardiovascular medicine at the Cleveland Clinic, the recent disappointing results with other medicines means one thing: if researchers want to know whether a new drug reduces the number of heart attacks in a given population, they must design a study that measures the number of heart attacks in that population. "Changing a biochemical marker is not the same as improving the outcome for patients," Nissen insists. As much as physicians and their patients might wish it otherwise, cardiovascular disease has complex causes, and changing one or two factors that contribute to it will not always be enough to guarantee good health. In the meantime, in addition to taking prescribed medicines, Baylor's Ballantyne says, people at risk for heart disease and stroke would be wise to use all the weapons at their disposal—such as exercising, if their doctors approve of it—and watching what they eat. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/nov2011

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

The Joke's on Your Computer

Programmers continue to plug humorous gems into everyday software

In Google Maps, the distance-measuring tool offers a choice of three unit systems: Metric, English or "I'm Feeling Geeky." If you click the third one, you're offered a long list of, ahem, somewhat uncommon measurement units, including parsecs, Persian cubits, and Olympic swimming pools.

Mac OS X's text-to-speech feature, meanwhile, lets you endow your Mac with any of dozens of different human voices. Each speaks a funny sample sentence. The Fred voice says, "I sure like being inside this fancy computer." The quaking, semihysterical Deranged voice says, "I need to go on a really long vacation." The alien-sounding Trinoids voice says, "We cannot communicate with these carbon units."

On YouTube, if you pause a video and hold down the up and left arrow keys, you trigger a secret game of Snake. Try to guide the increasingly long snake's body around the screen with your arrow keys without tripping over yourself.

In each of these cases, some programmer deep inside these megalithic corporations exhibited a sense of humor—a display that somehow made it past committee, through the lawyers and out into the world.

In the olden days—10 or 20 years ago—this sort of playfulness in software was more common. Software engineers took pride in embedding into their code all manner of jokes, whimsy and Easter eggs (hidden surprises triggered by unlikely sequences of keystrokes).

Some of it was simple pride. Easter eggs often took the form of programming credits; after all, programmers usually don't get any public recognition, not even in the user guide.

Often the buried humor in software consisted of elaborate inside jokes. In the original system software for the Palm Pilot, for example, programmer Ron Marianetti created an animated taxicab, resembling a fat Volkswagen Beetle, programmed to race across the screen at random times—a tribute to the Pilot's original proposed name, the Taxi.

Across the hall, fellow engineer Chris Raff embedded an Easter egg of his own. If you held down your stylus in the lower right corner of the handwriting-practice game screen and then pressed a scroll button, a photo of himself with a buddy, tuxedoed at Palm's annual Christmas party, would inexplicably appear.

In time, though, Silicon Valley's corporate bosses began to frown on the practice of burying jokes in software. Part of the reason was quality control: by definition, an Easter egg is an untested feature. It's a loose cannon that could, in theory, interfere with other, more important parts of the program. It made the overlords nervous.

Another problem was employee retention. When programmers buried their own names into their work, they were, in essence, advertising their own skills. Their names were clearly displayed for inspection by headhunters at rival software companies.

Finally, there's the simple matter of corporate image. An Apple or a Microsoft or a Palm may spend millions to create a certain public image of professionalism. The last thing its image meisters want is some rogue animation of a taxi driving across the screen during an important public demo. (Which actually happened to Palm. The taxi Easter egg was removed shortly thereafter.)

BY DEFINITION, AN EASTER EGG
is an untested feature.
It made the overlords nervous.

These days, the spirit of in-jokes and whimsy lives on, but it has moved to new addresses: video games and movies—especially movies on DVD. Software jokes still live on in mainstream apps, but they're less ambitious, and most of them seem to come from Apple and, especially, Google.

Inside jokes lurk on the icon for Apple's TextEdit, for example (view the icon at the largest possible size). Or turn on the Mac's Speech Recognition feature and say to your computer, "Tell me a joke."

Or search Google for "recursion" and click the "Did you mean?" suggestion. Or call up the Sydney Opera House in Google Earth and then spin around to the waterfront side; a late, great TV celebrity waits for you there. Or ask Google Maps to give you the directions from Japan to China and marvel at Google's suggestion for getting across the Pacific (step number 42).

Thank you, anonymous programmers; keep it up. You've made it clear that software can do more than make us productive—it can also make us happy. SA

SCIENTIFIC AMERICAN ONLINE
The most elaborate Easter eggs of all time:
ScientificAmerican.com/nov2011/pogue

THE 1st AMERICANS

Humans colonized the New World earlier than previously thought—a revelation that is forcing scientists to rethink long-standing ideas about these trailblazers

By Heather Pringle

IN THE SWELTERING HEAT OF AN EARLY JULY AFTERNOON, MICHAEL R. Waters clambers down into a shadowy pit where a small hive of excavators edge their trowels into an ancient floodplain. A murmur rises from the crew, and one of the diggers gives Waters, an archaeologist at the Center for the Study of the First Americans at Texas A&M University, a dirt-smeared fragment of blue-gray stone called chert. Waters turns it over in his hand, then scrutinizes it under a magnifying loupe. The find, scarcely larger than a thumbnail, is part of an all-purpose cutting tool, an ice age equivalent of a box cutter. Tossed away long ago on this grassy Texas creek bank, it is one among thousands of artifacts here that are pushing back the history of humans in the New World and shining rare light on the earliest Americans.

Illustration by Tyler Jacobsen

Heather Pringle is a Canadian science writer and a contributing editor to *Archaeology* magazine.

Waters, a tall, rumpled man in his mid-fifties with intense blue eyes and a slow, cautious way of talking, does not look or sound like a maverick. But his work is helping to topple an enduring model for the peopling of the New World. For decades scientists thought the first Americans were Asian big-game hunters who tracked mammoths and other large prey eastward across a now submerged landmass known as Beringia that joined northern Asia to Alaska. Arriving in the Americas some 13,000 years ago, these colonists were said to have journeyed rapidly overland along an ice-free corridor that stretched from the Yukon to southern Alberta, leaving behind their distinctive stone tools across what is now the contiguous U.S. Archaeologists called these hunters the Clovis people, after a site near Clovis, N.M., where many of their tools came to light.

Over the past decade or so this Clovis First model has come under sharp attack as a result of new discoveries. In southern Chile, at a site known as Monte Verde, archaeologist Thomas D. Dillehay, now at Vanderbilt University, and his colleagues found traces of early Americans who slept in hide-covered tents and dined on seafood and a wild variety of potato 14,600 years ago, long before the appearance of Clovis hunters. Intrigued by the findings, some scientists began looking for similar evidence in North America. They found it: in Paisley Five Mile Point Caves in Oregon, for example, a team uncovered 14,400-year-old human feces flecked with seeds from desert parsley and other plants—not the kinds of comestibles that advocates of the big-game hunters scenario expected to find on the menu. "What we are seeing," says Dennis L. Jenkins, director of the Paisley Caves dig and an archaeologist at the Museum of Natural and Cultural History in Eugene, Ore., "is a broad-range foraging economy."

Now, along Buttermilk Creek, Waters and his team have made one of the most important finds yet: a mother lode of stone tools dating back a stunning 15,500 years ago. In all, the team has excavated more than 19,000 pre-Clovis artifacts—from small blades bearing tiny wear marks from cutting bone to a polished chunk of hematite, an iron mineral commonly used in the Paleolithic world for making a red pigment. Publicly unveiled this past spring, the site has yielded more pre-Clovis tools than all other such sites combined, and Waters has spared no expense in dating each layer multiple times. The work has impressed many experts. "It is easily the best evidence for pre-Clovis in North America," says Vance T. Holliday, an anthropologist and geoscientist at the University of Arizona.

Energized by such finds, archaeologists are now testing new models for the peopling of the New World. Drawing on evidence from a range of sciences—from genetics to geology—they are searching for answers to a host of pressing questions: Where did the earliest Americans come from more than 15,500 years ago? When exactly did they arrive, and what route did they take into the New World? For the first time in decades there is a heady whiff of discovery in the air. "We are now addressing the big issues," says James M. Adovasio, an archaeologist at Mercyhurst College. "We are looking at the circumstances of the dispersal of humans into the last great habitat on the planet."

GENETIC TRAILS

THE PEOPLING OF THE NEW WORLD, from the blustery cold of the Arctic to the sultry heat of the Amazon and the stormy winds of Tierra del Fuego, remains one of humanity's greatest achievements, a feat of endurance and adaptation not to be equaled, in the view of the famous 20th-century French archaeologist François Bordes, "until man lands on a planet belonging to another star." Yet archaeologists have long struggled to uncover the beginnings of this transcontinental adventure, given the daunting task of locating the early campsites of a tiny population of highly mobile hunters and gatherers in the vast northern wildernesses of North America and Asia. Over the past decade, however, geneticists have taken the search for the first Americans to the molecular level, finding new clues to where they hailed from and when they left their homeland in the DNA of indigenous peoples.

In more than a dozen studies geneticists examined modern and ancient DNA samples from Native Americans, looking for telltale genetic mutations or markers that define major human lineages known as haplogroups. They found that native peoples in the Americas stemmed from four major founding maternal haplogroups—A, B, C and D—and two major founding paternal haplogroups—C and Q. To find the probable source of these haplogroups, the teams then searched for human populations in the Old World whose genetic diversity encompassed all the lineages. Only the modern inhabitants of southern Siberia, from the Altai Mountains in the west to the Amur River in the east, matched this genetic profile, a finding that strongly indicates that the ancestors of the first Americans came from an East Asian homeland.

This evidence confirmed what most archaeologists suspected about the location of this homeland. It also strongly suggested that the timing proposed in the Clovis First scenario was wrong. Geneticists now calculate, based on mutation rates in human DNA, that the ancestors of the Native Americans parted from their kin in their East Asian homeland sometime between 25,000 and 15,000 years ago—a difficult time for a great northern migration. Huge glaciers capped the mountain valleys of northeastern Asia, at the same time massive ice sheets mantled most of Canada, New England and several northern states. Indeed, reconstructions of past climate based on data preserved in ice cores from Greenland and on measurements of past global sea levels show that these ice sheets reached their maximum extent in the last glacial period be-

IN BRIEF

Archaeologists long thought the first Americans were the Clovis people, who were said to have reached the New World some 13,000 years ago from northern Asia.

But fresh archaeological finds prove that humans reached the Americas thousands of years before that. **These discoveries,** along with insights from genetics and geology, have prompted reconsideration of where these pioneers came from, when they arrived and what route they took into the New World.

tween at least 22,000 and 19,000 years ago. "But these folks were extraordinarily adept at moving over the landscape," says David Meltzer, an archaeologist at Southern Methodist University. "Their entire existence—and the existence of everyone they knew and the existence of their ancestors—was about adapting. They had a toolbox of tactics and strategies."

It was a land empty of human rivals, a new world of possibilities.

Dressed in warm, tailored hide garments stitched together with sinew and bone needles and armed with an expert knowledge of nature, the ancestors of the Paleo-Americans entered an Arctic world without parallel today. The ice sheets in northern Europe and North America had locked up vast quantities of water, lowering sea level by more than 100 meters and exposing the continental shelves of northeastern Asia and Alaska. These newly revealed lands, together with adjacent regions in Siberia, Alaska and northern Canada, formed a landmass that joined the Old World seamlessly to the New.

Known today as Beringia, this landmass would have made a welcoming way station for pre-Clovis migrants. The air masses that swept over it were so dry they brought little snowfall, preventing the growth of ice sheets. As a result, grasses, sedges and other cold-adapted plants thrived there, as shown by plant remains found preserved under a layer of volcanic ash in northwestern Alaska and in the frozen intestines of large herbivores that once grazed in Beringia. These plants formed an arid tundra-grassland, and there woolly mammoths weighing as much as nine tons grazed, as did giant ground sloths, steppe bison, musk ox and caribou. Genetic studies of modern Steller's sea lion populations suggest that this sea mammal likely hauled out on the rocks along Beringia's island-studded south shore. So the migrants may have had their pick not only of terrestrial mammals but also of seafaring ones.

Received wisdom holds that the trailblazers hurried across Beringia to reach warmer, more hospitable lands. Some researchers, however, think the journey could have been a more leisurely affair. The major genetic lineages of Native Americans possess many widespread founding haplotypes—combinations of closely linked DNA sequences on individual chromosomes that are often inherited together—that their closest Asian kin lack. This suggests the earliest Americans paused somewhere en route to the New World, evolving in isolation for thousands of years before entering the Americas. The most likely spot for this genetic incubator is Beringia. There the migrants could conceivably have been cut off from their Asian kin as the climate cooled some 22,000 years ago, forcing Siberian bands to retreat south.

Whether the migrants cooled their heels in Beringia, however, or somewhere else in northeastern Asia, people eventually began striking off farther east and south. A warming trend began slowly shrinking North America's ice sheets some 19,000 years ago, gradually creating two passable routes to the south and opening the possibility of multiple early migrations. According to several studies conducted over the past decade on the geographic distribution of genetic diversity in modern indigenous Americans, the earliest of these migrants started colonizing the New World between 18,000 and 15,000 years ago—a date that fits well with emerging archaeological evidence of pre-Clovis colonists. "At some point, these migrants surveyed the landscape and realized for the first time that smoke from all the other campfires was behind them, and ahead there was no smoke." Adovasio reflects. "And at that moment, they were literally strangers in a strange land."

A COASTAL ROUTE

ARCHAEOLOGISTS take up the tale of the earliest Americans as these travelers pushed southward, exploring a wilderness untouched by humans. In an office decorated with prints and pictures of sharks and a poster of a traditional Chumash wood canoe, Jon M. Erlandson, an archaeologist at the University of Oregon, mulls over new evidence of their journey. Reed-thin, tousled and in his mid-fifties, Erlandson has spent much of his career digging at sites along the coast of California, becoming one of the foremost proponents of what is often called the coastal route theory. Whereas supporters of the Clovis First model envisioned humans reaching the Americas by trekking overland, Erlandson thinks the earliest travelers arrived by sea, paddling small boats from East Asia to southern Beringia and down the western coast of the Americas. Now he and his colleague Todd J. Braje of San Diego State University have uncovered key new evidence of ancient mariners who set out in East Asia and ended their journey in Chile.

Scientists first began thinking about this coastal route in the late 1970s, when archaeologist Knut Fladmark, now a professor emeritus at Simon Fraser University in British Columbia, started examining geologic and pollen records to reconstruct ancient environments along Canada's western coast. At the time, most experts believed that the entire northwestern coast lay under thick ice until the end of the last glacial period. Analyses published in the 1960s and 1970s of ancient pollen from coastal bogs, however, showed that a coniferous forest thrived on Washington's Olympic Peninsula 13,000 years ago and that other green refugia dotted the coast. Early humans camping in these spots, Fladmark concluded, could have fueled up on seafood, from shellfish to migrating pink salmon. They may also have hunted waterfowl migrating along the Pacific flyway, as well as caribou and other hardy land animals grazing in the larger refugia.

Archaeologists now know that much of the British Columbian coast was free of ice at least 16,000 years ago. Although they have yet to find any preserved boats in early American coastal sites, many researchers think such watercraft were probably available to these wayfarers: at least 45,000 years ago humans voyaged and island-hopped all the way from Asia to Australia. Traveling by water down the western coast of the New World would have been easier in many respects than trekking overland. "It's an environment that's relatively similar along a north-south transect, which makes it a path of least resistance," says Quentin Mackie, an archaeologist at the University of Victoria in British Columbia.

Still, finding campsites of early mariners has proved a tall order for scientists. As the ice sheets of the last glacial period thawed, the meltwater raised sea level, drowning ancient coastlines under meters of water. Last March, however, Erlandson and Braje detailed in the journal *Science* striking evidence of early seafarers at a newly discovered site on Santa Rosa Island located just off the southern California coast. Nearly 12,000 years ago Paleo-American sailors crossed 10 kilometers of open water to reach Santa Rosa, a journey that would have required a boat.

The newly discovered site, known as CA-SRI-512W, lies near

A Precocious Peopling

In the traditional view of human colonization of the Americas, big-game hunters from Asia—the so-called Clovis people—swept quickly across a now submerged landmass called Beringia into North America around 13,000 years ago and hastened south into warmer climes. Over the past decade, however, evidence against this "Clovis First" scenario has mounted. The latest geologic and archaeological research indicates that humans entered the New World thousands of years before the Clovis people left behind their distinctive stone tools and suggests two possible migration paths: a coastal route and an early ice-free corridor.

Land Route: Ice-Free Corridor

According to the Clovis First model, the Cordilleran and Laurentide ice sheets did not part ways until 13,000 years ago, thus barring a pre-Clovis overland migration into the Americas. But fresh geologic data indicate that the corridor opened by 15,000 years ago. Travelers along this route may have hunted birds and brought dogs with them to carry their gear. Trekking 16 kilometers a day, the migrants could have reached the end of the corridor in four months.

Actual size

KEY FIND: SANTA ROSA ISLAND, CALIF.

Distinctive, Christmas tree–shaped stone points found at Santa Rosa Island date to 11,800 years ago and resemble stone tools from East Asia that date to 15,000 years ago, hinting at an early migration route along the northern Pacific Rim.

FAMOUS ASSEMBLAGE: CLOVIS, N. M.

In the 1930s discoveries at Blackwater Locality No. 1 near Clovis, N.M., and other sites yielded long, sturdy, fluted spearpoints for hunting large-game animals such as woolly mammoths. For years these Clovis points and other artifacts had the distinction of being the oldest in the New World and formed the basis of the Clovis First model of the peopling of the Americas.

Actual size

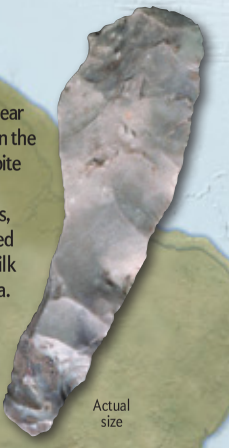
Coastal Route

Explorers from East Asia may have paddled small boats to southern Beringia and down the western coast of the Americas starting as early as 16,000 years ago. The British Columbian coast was rid of ice by then, and migrants would have had access to a bounty of marine mammals and fish. The earliest known site near the coast, Monte Verde in Chile, dates to just 14,600 years ago; however, the thawing of the ice sheets during the last glacial period may have drowned the oldest sites along the ancient coastline.

PACIFIC OCEAN

KEY FIND: FRIEDKIN SITE, TEX.

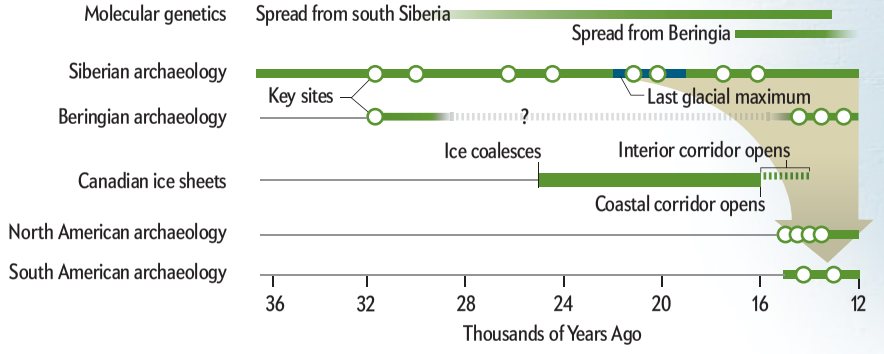
With thousands of artifacts securely dated to 15,500 years ago, this site near Buttermilk Creek in Texas is the nail in the coffin of the Clovis First theory. Despite their antiquity, the remains exhibit features in common with Clovis tools, hinting that Clovis hunters descended from bands like the ones at Buttermilk Creek, rather than originating in Asia.



Actual size

SOUTH AMERICA

Monte Verde, Chile



Lines of Evidence

Taken together, genetic, archaeological and geologic records suggest that humans set out from Siberia sometime between roughly 25,000 and 15,000 years ago, entering the New World via Beringia as the ice sheets blanketing the Pacific coastal corridor and the interior corridor of North America receded. By 14,600 years ago they had made their way to South America.

Illustration by Tyler Jacobson, Map by XNR Productions

COURTESY OF JON M. ERLANDSON *University of Oregon* (*Santa Rosa spearhead*); COURTESY OF MICHAEL R. WATERS *Texas A&M University* (*Clovis and Friedkin spearheads*); FROM "THE LATE PLEISTOCENE DISPERSAL OF MODERN HUMANS IN THE AMERICAS," BY TED GOEBEL ET AL., IN *SCIENCE*, VOL. 319; MARCH 14, 2008 (*timeline: glacial maximum and corridor opening dates have been updated with other sources*); CONSULTANTS: KENNEDY MUNYIKWA *Athabasca University* AND MICHAEL R. WATERS (*ice sheets*); QUENTIN MACKIE *University of Victoria* (*coastal route vignette*); STUART J. FIEDEL *Louis Berger Group* AND BEN POTTER *University of Alaska Fairbanks* (*land route*)

THE WORLD NEEDS MORE THAN OIL.

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Professor Alan Robson
Vice-Chancellor
University of Western Australia

Neil Theobald
General Manager,
Gas Marketing & Commercialization
Chevron

the mouth of an inland canyon and close to what might have been an ancient marsh. Erlandson and his team found human refuse buried in the sediments, including bird bones and charcoal the researchers radiocarbon-dated to 11,800 years ago. Early coastal hunters had dined there on waterfowl and seabirds such as Canada geese and cormorants, as well as on pinnipeds, a group that encompasses seals and sea lions. The hunters also left behind traces of a distinctive technology: more than 50 dainty stemmed points that looked in outline like little brown Christmas trees. Such points may have tipped darts for hunting birds or small marine mammals. "They are just extremely thin and extremely well made," Erlandson says. Overall, their design and manufacture seemed very unlike the long, furrowed and sturdy-looking Clovis spearpoints used by big-game hunters on the mainland.

Curious about the origin of this coastal technology, Erlandson and Braje scoured published archaeological reports on other sites for clues. They discovered that excavators had dug up very similar stemmed points at ancient sites scattered around the northern rim of the Pacific Ocean. The earliest came from East Asia—the Korean peninsula, Japan and the Russian Far East—and all dated to around 15,000 years ago. Moreover, the farther one traveled away from there, the younger these weapons were, with 14,000-year-old stemmed points in Oregon and 12,000-year-old points on the Channel Islands, in Baja California and along coastal South America. Erlandson shakes his head in wonderment. "Some of the point assemblages in Japan are really similar to the ones in the Channel Islands," he says.

Erlandson and Braje now think this trail of technology marks out an early migration route along the northern Pacific Rim, a coastal highway loaded with food. Kelp, for example, flourishes in the cold, nutrient-rich waters there, forming coastal marine forests that harbor species ranging from rockfish to abalone to sea otters. Such marine forests would likely have thrived along Beringia's southern coast even during the last glacial period. Studies of ocean temperature some 18,000 years ago suggest that sea ice formed only in winter along Beringia's southern coast, and this seasonal deep freeze would not have eradicated the great marine forests. Kelp can survive under sea ice in a state akin to suspended animation for long months at a time, growing rapidly again when summer arrives and creating an abundant marine habitat. "And it's not just kelp that would have facilitated a coastal migration," Erlandson says. "There's an enormous amount of other resources in marine estuaries and in salmon streams." Indeed, edible species along the route today number in the hundreds, from cetaceans to seaweed.

Even so, Paleo-Americans exploring this rich coastal world were unlikely to have raced southward. Indeed, some researchers think they may have moved just a kilometer or so a year, as the migrants gradually expanded the southern boundaries of their hunting and gathering territory. "This wasn't a sprint down the coast," Erlandson concludes. "You had to have marriage partners because you were moving into unpopulated lands. So you had to maintain connections with people behind you."

AN INLAND CORRIDOR

THE WESTERN COAST of the Americas was not the only available route for early colonists. Over the past five years a team of earth scientists and dating experts led by Kennedy Munyikwa, a geologist at Athabasca University in Alberta, has been reexamining another potential passageway, one that was widely championed by supporters of the Clovis First theory but that later fell out of favor after the discovery of pre-Clovis people at the site of Monte Verde near the Chilean coast. Known as the ice-free corridor, this midcontinental route formed after North America's largest ice sheet, the Laurentide, began retreating eastward, separating from the Cordilleran ice sheet that blanketed the west, and after vast glacial lakes blocking the passageway drained, leaving dry land. The resulting corridor ran along the eastern flanks of the Rockies and extended nearly 1,900 kilometers, from Alaska to the lower 48 states.

The renewed interest in this route stems from new dates on the opening of the corridor that Munyikwa and his colleagues published in June in the journal *Quaternary Geochronology*. In the 1980s researchers at the Geological Survey of Canada dated its opening by radiocarbon-testing plant remains preserved in sediments along the route. Their findings indicated that the two colossal ice sheets parted company and that the glacial lakes drained around 13,000 years ago. This time frame fit well with the Clovis First scenario, although it ruled out the corridor as a migration route for earlier people.

Yet as Munyikwa examined these early studies for a project on ancient environment change, he saw serious problems. The radiocarbon dates were few in number, and some were clearly unreliable. Moreover, the dating of plants determined when vegetation had finally reestablished itself in the corridor, not when the ice had actually retreated and the lakes drained. So Munyikwa and his colleagues decided to redate the opening of the ice-free corridor by a technique known as optically stimulated luminescence (OSL). The team focused on a section of the corridor in northern Alberta, where large sand dunes—some exceeding 10 meters in height—had formed from windblown sediments after the Laurentide ice sheet retreated.

To obtain samples for dating, Munyikwa and his team cut pits into the tallest dunes in these fields. Then they hammered black plastic pipes horizontally into the walls of these pits. Capped on one end, the pipes filled with sand that had not been exposed to sunlight since the dunes accumulated. Next the team dated each sample by the OSL method, measuring the amount of energy from environmental radiation trapped in minerals such as feldspar in the samples. The results showed that the sand dunes formed between 14,000 and 15,000 years ago, a range that likely constitutes a minimum age for the opening of the corridor, Munyikwa says, because "it's possible that the dunes formed 1,000 years after the ice went away." Moreover, the corridor in northern Alberta stretched at least 400 kilometers across at this time and likely cradled few if any large meltwater lakes. The sand that accumulated in dunes, Munyikwa points out, came from dry lake bottoms.

The big question now is whether the entire corridor lay open during this period, particularly the section to the north. Munyikwa thinks it did. His team recently dated sand dunes farther north, along the Alberta-Northwest Territory border, with similar results. These data, Munyikwa says, fit current thinking about the Laurentide ice sheet. The general consensus among geologists, he notes, "is that the ice sheet retreated in a northeasterly direction as a wide front, as opposed to [moving] in discrete lobes. We envisage that the deglaciated land extended to the north." If so, explorers from Asia could have entered the corridor around 15,000 years ago, nearly 1,000 years after the route to the western coast opened.

The new OSL dates, says archaeologist Jack Ives of the Univer-

Dig near Buttermilk Creek in Texas has yielded artifacts that clearly predate the Clovis culture. Hunters may have come here to exploit the local chert stone to make tools.

sity of Alberta in Edmonton, will prompt a fresh look at this corridor, rekindling a major debate over migration routes. "It is often alleged, in grave error, that the corridor region has been well investigated, when in fact it is vast, and we know little about it," Ives asserts. The oldest, broadly accepted evidence of humans in the northern corridor dates to some 12,000 years ago, but Ives thinks future archaeological surveying could well turn up much earlier sites. "I think if the coast was Highway 1, then the corridor was Highway 2," he quips.

Scoured by retreating ice and pierced by cold winds, the newly opened corridor would have seemed a formidable place to early travelers. Yet it is possible, argues Stuart J. Fiedel, an archaeologist at the Louis Berger Group in East Orange, N.J., that hunter-gatherers in Beringia decided to explore it after watching flocks of waterfowl head south in the fall and return in the spring. Food would have been scarce, Fiedel says, but the explorers may have hunted calorie-rich birds or larger game. Recent genetic data suggest that mountain sheep grazed in two refugia in the Yukon and northern British Columbia.

As an insurance policy, the travelers may have taken along man's best friend. Hunters in Siberia seem to have first domesticated wolves as early as 33,000 years ago, based on paleontological evidence. Fiedel thinks early dogs would have made invaluable hunting companions and pack animals on a journey through the corridor. In historic times, he notes, hunter-gatherers on the Great Plains placed pack saddles on dogs or hitched them to travoises to carry a variety of loads, from hides for bedding and shelter to food stores. Experiments have shown that dogs can haul about 27 kilograms, Fiedel says. Moreover, a study published in 1994 revealed that dogs carrying 13 kilograms of gear could travel as far as 27 kilometers a day, provided the temperature remained cool. If starvation threatened, the migrants could have eaten some of their dogs.

Fiedel has calculated that the colonists could have reached the southern end of the corridor in four months, traveling at a modest pace of 16 kilometers a day. As they left its stony bleakness behind, they would have laid eyes for the first time on a breathtaking abundance: warm, grassy plains filled with herds of mammoths, bison and horses; marshes and lakes dotted with waterfowl; oceans brimming with fish and marine mammals. It was a land empty of human rivals, a new world of possibilities.

CLOVIS ORIGINS

IN THE SHADY air-conditioned house that serves as the field-camp headquarters at Buttermilk Creek, Waters lifts off the lid from a black box the size of a small laptop. In the kitchen, members of his crew chat and joke as they prepare lunch, but Waters seems oblivious to the patter. He quickly scans the contents of the box, picks up first one, then another of the 20 or so pre-Clovis stone tools lying inside. Fashioned from a lustrous local chert found near Buttermilk Creek, the blades and other tools are remarkably compact and lightweight, some measuring no more than a few centimeters in length. Such a tool kit, Waters says, would have been ideal for bands of early explorers, a people constantly on the move as they probed and investigated terra incognita.

In some of these tools—particularly the blades and bifaces—Waters also sees something else: a new clue to the origins of the Clovis people. Some 2,500 years after the pre-Clovis people here knapped blades and bifaces, Clovis hunters employed similar techniques across North America to make massive elongate blades, some reaching 21 centimeters or more in length. This technological continuity, Waters observes, hints strongly at a relationship between the two groups. Far from being migrants from Asia, the famous Clovis hunters may well have descended from bands such as the earliest hunters at Buttermilk Creek. "It looks as if they originated south of the ice sheet," he remarks.

What is beyond all doubt, however, is that the earliest Americans and their descendants were a resilient and resourceful people, trailblazers who settled the longest geographic expanse ever settled by humans. Braving the unknown, they adapted masterfully to a vast array of ecosystems on two continents. These early Americans deserve our admiration, says archaeologist David Anderson of the University of Tennessee. "I think they exemplify the spirit of survival and adventure that represents the very best of humanity." SA

MORE TO EXPLORE

Paleoindian Seafaring, Maritime Technologies, and Coastal Foraging on California's Channel Islands. Jon M. Erlandson et al. in *Science*, Vol. 331, pages 1181–1185; March 4, 2011.

The Buttermilk Creek Complex and the Origins of Clovis at the Debra L. Friedkin Site, Texas. Michael R. Waters et al. in *Science*, Vol. 331, pages 1599–1603; March 25, 2011.

Constraining the Late Wisconsinan Retreat of the Laurentide Ice Sheet from Western Canada Using Luminescence Ages from Postglacial Aeolian Dunes. Kennedy Munyikwa et al. in *Quaternary Geochronology*, Vol. 6, No. 4, pages 407–422; June 2011.

SCIENTIFIC AMERICAN ONLINE

Interactive map of Paleo-American sites and possible migration routes: ScientificAmerican.com/nov2011/pringle

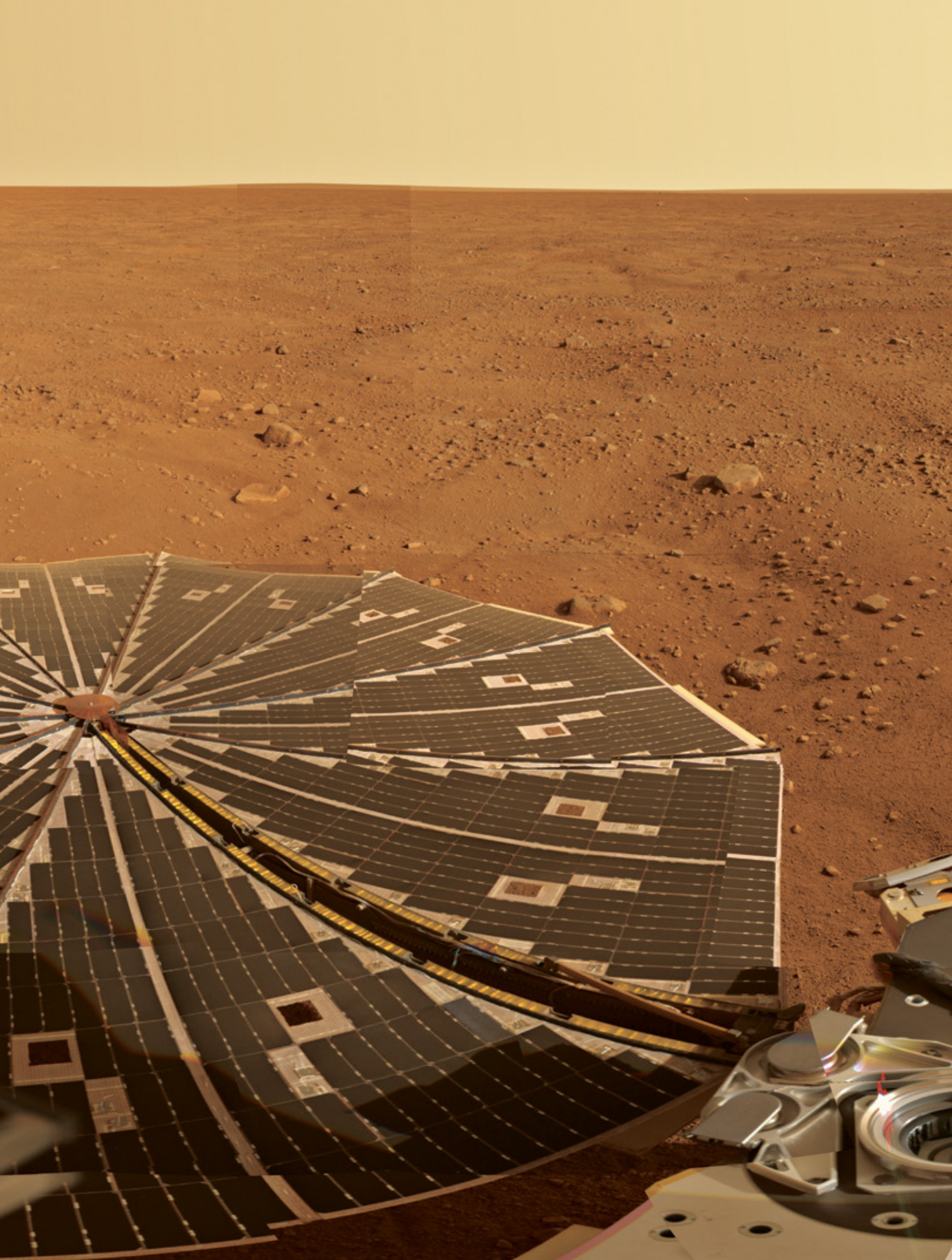
COURTESY OF MICHAEL R. WATERS *Texas A&M University*

DIGGING MARS

The Mars Phoenix mission revived hopes that the Red Planet may be habitable, preparing the way for a new rover to be launched this month

By Peter H. Smith

Partial panorama of the Mars Phoenix landing site shows one of the two solar arrays and, beyond it, the polygonally patterned terrain that is characteristic of permafrost on both Mars and Earth. (The full panorama is available at photo journal.jpl.nasa.gov/catalog/PIA13804.)



Peter H. Smith is a professor of planetary science at the University of Arizona. As a child, he virtually explored the solar system as an avid science-fiction reader. Turning this early love into an avocation, he has worked on some of the most famous robotic planetary missions, from the Pioneer 11 deep-space probe to the Sojourner, Spirit and Opportunity rovers. Last year NASA awarded him the Exceptional Scientific Achievement Medal.

THIS MONTH NASA PLANS TO LAUNCH ITS LATEST AND MOST SOPHISTICATED MISSION EVER to the Red Planet: the Mars Science Laboratory. After a dramatic landing in Gale Crater using a skycrane for the final descent, the nuclear-powered rover will drive around one of the richest deposits of clays and sulfates on the planet—the remains of a water-rich era when rivers carved out valley networks.

The size of a small car, the rover (named Curiosity) will spend a Martian year exploring the base of the central peak in the crater, thought to be the oldest section. Then, if NASA approves an extended mission, Curiosity will begin to climb the five-kilometer-high debris pile that fills the center of the crater, moving up the geologic timeline toward deposits made in the modern era, scrutinizing the aqueous minerals layer by layer. A robot arm can retrieve samples and feed them to an onboard chemistry lab through a port on top of the rover. Inside, analyzers will determine the mineral structures and elemental composition. These instruments also can sense organic materials and will attempt to decide whether Mars used to be habitable.

The Mars Science Laboratory is a logical step in the progression of missions over the past 15 years and builds on the findings of the Sojourner, Spirit and Opportunity rovers and of the most recent lander, Phoenix. These missions, along with a series of orbiters, have revealed a world of remarkable complexity and tangled history, including a bygone epoch of lakes and rain [see "The Red Planet's Watery Past," by Jim Bell; SCIENTIFIC AMERICAN, December 2006]. Even in its present dry, frozen state, the planet shows signs of activity. Among the most exhilarating and puzzling are the hints of methane gas above the Nili Fossae region. Planetary scientists debate whether the gas, if real, has a geologic or biological origin [see "The Mystery of Methane on Mars and Titan," by Sushil K. Atreya; SCIENTIFIC AMERICAN, May 2007]. This year the Mars Reconnaissance Orbiter revealed surface streaks that can be most easily explained by the seasonal release of briny water.

Set against all these wonders, though, are the stark conclusions of the twin Viking landers of 1976. They found Mars to be exceptionally hostile to any living creature. The soils lacked water and organic molecules, let alone dormant microbes. Powerful oxidants such as hydrogen peroxide and intense ultraviolet radiation sterilized the surface. For most scientists, the search for life on Mars began and ended with Viking.

How do we reconcile that gloomy assessment with the planet's undoubted wonders? The answer may lie with Phoenix. Its chemical experiments on Martian soil, the first since Viking's, suggest an alternative interpretation of the Viking null results: perhaps Viking detected no organic molecules because the analysis technique inadvertently destroyed them. Phoenix also discovered near-surface water ice, which planetary scientists had hypothesized but had never actually seen. Not dry and barren, our neighboring planet may well still be habitable.

As the implications sink in and another craft sets out to follow up, now seems an apt time to look back at the technical and emotional roller coaster of mounting an interplanetary mission—and at how the Phoenix almost did not fly.

IN BRIEF

After a two-year delay, the Mars Science Laboratory is ready to blast off this month, carrying the most sophisticated surface-analysis package ever sent to Mars.

The questions it will address were determined in part by the Mars Phoenix mission of 2008, which revealed that Martian soil might not be nearly as hostile to living things as the Viking mission of 1976 suggested.

Phoenix discovered not only substances that Mars scientists had always suspected but never actually seen—such as subsurface water ice and calcium carbonate—but also the unexpected, including perchlorates and snowflakes.

COURTESY OF NASA/JPL-CALTECH, UNIVERSITY OF ARIZONA AND TEXAS A&M UNIVERSITY (*preceding pages*)

OUT OF THE ASHES

IT IS NOT EVERY DAY that someone calls to offer you a free spacecraft. Early in 2002 several scientists at the NASA Ames Research Center did just that. They reminded me that a 10-foot box in a Lockheed Martin clean room in Denver held a mothballed Surveyor spacecraft. It was supposed to have been launched in 2001, but NASA canceled the flight after its twin, the Mars Polar Lander, was lost during landing in December 1999. The loss had been a crushing blow to the agency, coming just weeks after the Mars Climate Orbiter had disappeared during its orbit insertion maneuver, presumed destroyed. It was a blow to me personally, too: I led the team that had designed and built the lander's camera.

The Ames scientists wanted to refurbish the spacecraft as part of NASA's new Scout program and asked me to serve as the lead scientist. Stunned, I hesitated. I had participated in planetary exploration for more than a dozen years, and the constant travel, endless meetings and nonstop phone calls had lost their thrill and kept me from the scientific investigations that I had trained for.

Furthermore, at that point the new project had no funding, no proposal manager and no support from a large institution, and only a few months remained before the proposal due date. Yet there stirred in my heart the desire to lead a team to find those magical clues and unravel the twisted threads that entangled Mars science. In my heart, I never believed the Viking landers' results. How was it possible that they saw no organic material? Could it be hidden where a new mission with the proper design could find it?

For two weeks I wrestled with myself. I had to identify meaningful scientific objectives. The Surveyor spacecraft had been designed to land near the equator, sample the soil with a robotic arm and deploy a small rover to analyze nearby rocks. It also carried scientific instruments intended to prepare for an eventual human mission. We could not afford to carry the rover on a Scout budget and did not have to prepare for human missions. So new instruments could replace the old, but the choice would depend on our basic science goals, which were undefined.

At this moment, through a wonderful synchronicity, my Arizona colleague William Boynton went public with the discovery of near-surface water ice surrounding Mars's south polar cap. Boynton led the team that built and operated the gamma-ray spectrometer on the Mars Odyssey orbiter, an instrument that detects not only gamma rays but also neutrons, which probe the hydrogen concentration in the upper meter of soil. The instrument also saw hints of water in the northern plains, including a sliver of water-ice-rich soil located at maximum extent of the winter carbon dioxide ice cap. (This cap waxes and wanes with the seasons.) I put an X on my map to mark this spot and immediately began choosing instruments to follow up this discovery.

Peering under its belly a week after landing, Mars Phoenix spotted smooth white patches—presumably water ice exposed when the landing engines blew away dust. (The foreground is distorted. Phoenix is nearly on level ground.)

Earth has a similar permafrost zone surrounding the Arctic. It is the deep freezer of the planet and preserves signatures of the life-forms that have lived there. The ice can be hundreds of thousands of years old. I had heard at a Mars polar conference that Eske Willerslev of the University of Copenhagen had performed DNA analysis on samples of Greenland glacial ice and Siberian permafrost and found a huge diversity of plants, animals and other organisms. Would the same be true for Mars with ice that might be many millions of years old?

I put together a partnership among the University of Arizona, the NASA Jet Propulsion Laboratory and Lockheed Martin. We called our mission Phoenix because we were bringing the canceled Surveyor mission back to life like the mythological bird. So began the one-and-a-half-year ordeal of writing proposals and competing against 20 other mission concepts, culminating in an eight-hour site visit from NASA's review board. In August 2003 NASA selected us to be the first Scout mission to Mars. The launch date of August 2007 gave us four years to prepare.

COURTESY OF KENNETH KREMER AND MARCO DI LORENZO *NASA/JPL/UA/Max Planck Institute*

RADAR FEVER

WE UNPACKED THE SPACECRAFT. It looked like a giant butterfly: its body bristled with scientific instruments, and its two large solar panels resembled outspread wings. It crouched on three legs; its single appendage—the robot arm—poked out from the side.

The next four years were spent examining, reengineering, reexamining and testing to find the design flaws that had doomed its sister ship. In all, engineering teams at Lockheed Martin and JPL found about 25 major flaws. Arduous though the process of rooting out all those bugs was, it was still easier and cheaper than building a new spacecraft from scratch, which would have carried its own risks. Most were fairly easily corrected by adding heaters, reducing the parachute size and beefing up the structure. Some required changes to the software. But one flaw was not so easily understood or corrected.

The landing radar was a unit taken from an F-16 fighter plane in the late 1990s. When we conducted test drops in the Mojave Desert, the system made critical errors in altitude and suffered data dropouts at inopportune moments. We consulted with Honeywell, the radar's designer, to try to understand its inner workings. Despite the company's desire to help us, the obsolete model was no longer supported, the employees who had engineered it were gone and records were sketchy.

We formed a tiger team of engineers from Lockheed Martin, JPL, Honeywell and the NASA Langley Research Center. Combining computer simulations with further tests, the team slowly worked through a maze of anomalies to fix the flaws. In October 2006 we did a test—and it worked. All seemed well.

Then our hopes were dashed again. We discovered that reflections off the jettisoned heat shield could confuse the radar and cause a serious miscalculation of the altitude. Antennas and switches also proved failure-prone. The troubles seemed endless. By February 2007, just five months before we were scheduled to integrate the spacecraft with the launch vehicle, we had 65 anomalies under investigation.

Without a reliable radar, the launch was in doubt. NASA's review boards followed the situation closely and were concerned that we kept uncovering new fault modes. On the other hand, the severity of the anomalies was lessening. By June we were able to convince the review boards and our NASA managers that the remaining risks were acceptable. Still, it was a gamble. If we were continuing to find weaknesses up to time of launch, more could be buried within the system.

PHOENIX IN THE SKY

IN AUGUST 2007 we finished the final tests at the Kennedy Space Center and prepared to install the spacecraft on the Delta II launch vehicle. Then came a moment I wish I could forget. As the lift crane was hoisting the spacecraft to the top of the 130-foot-tall rocket, a major lightning storm broke out, and safety regulations forced technicians to evacuate the assembly tower. The spacecraft, its delicate electronic parts poorly protected,

STEVE LEE *University of Colorado*, JIM BELL *Cornell University*, MIKE WOLFF *Space Science Institute* AND NASA (*Mars base map*)

LANDING ON MARS

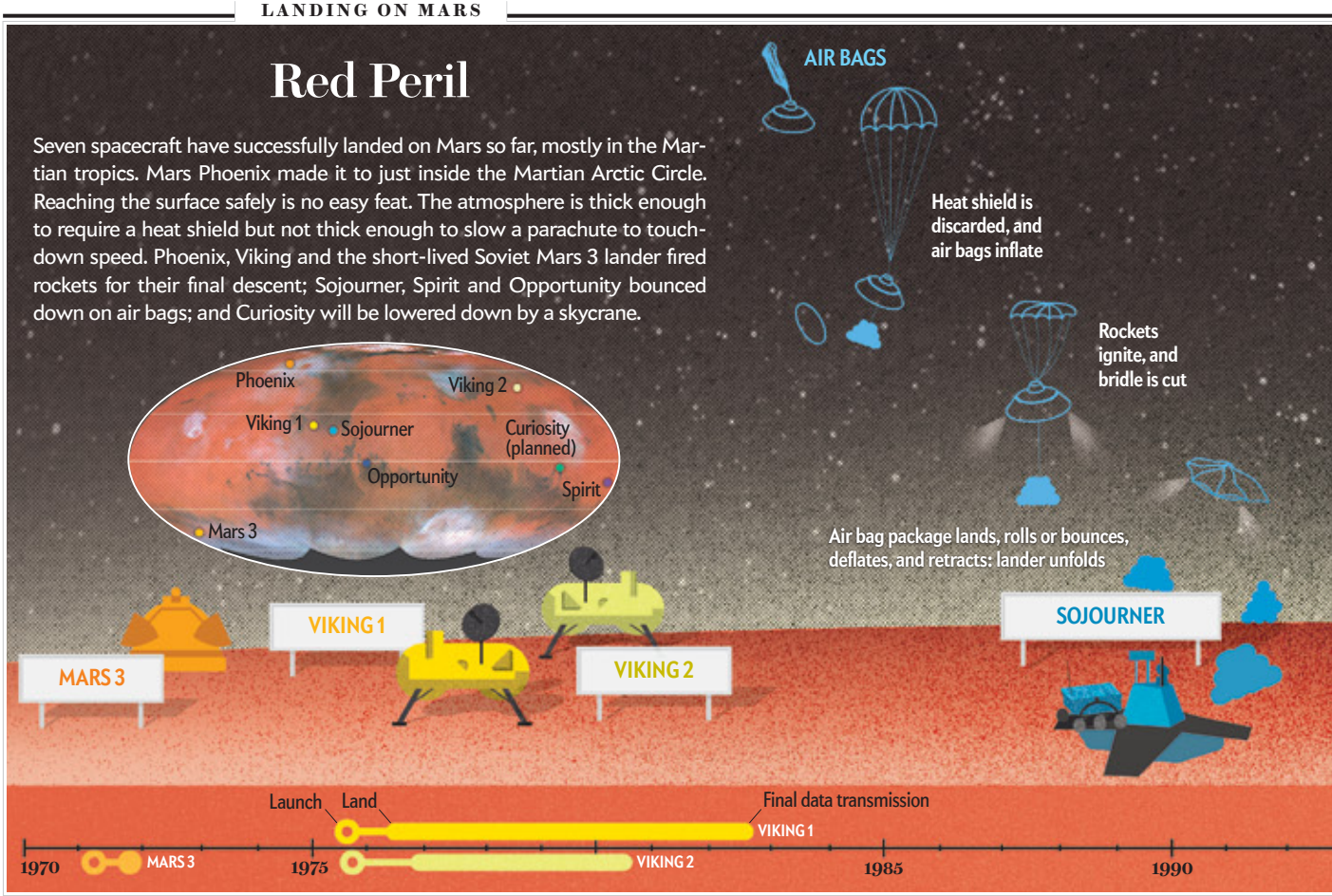


Illustration by Gavin Potenza

dangled 60 feet above the ground in a fearsome summer storm.

After the storm, we returned the spacecraft to the assembly building and desperately checked it for damage. Miraculously, we found none.

Early on August 4 the final countdown commenced. I scrambled out of the inner sanctum of the control room to view the launch directly. It was 5:15 A.M., and stars were clearly visible. Mars beckoned brightly in the east. Suddenly, the buildings lit up as though the sun were rising, and, silently, the rocket leaped into the sky; for a few seconds, the area was bright enough to read a book and see colors. Thirty seconds later the sound of the launch reached me, compressing my chest with the pressure waves created in the liftoff blast. The six solid rockets were jettisoned, dropping like sparklers into the Atlantic, and then the remaining three ignited. Phoenix was on its way. I then realized that I had not taken a breath in the longest time.

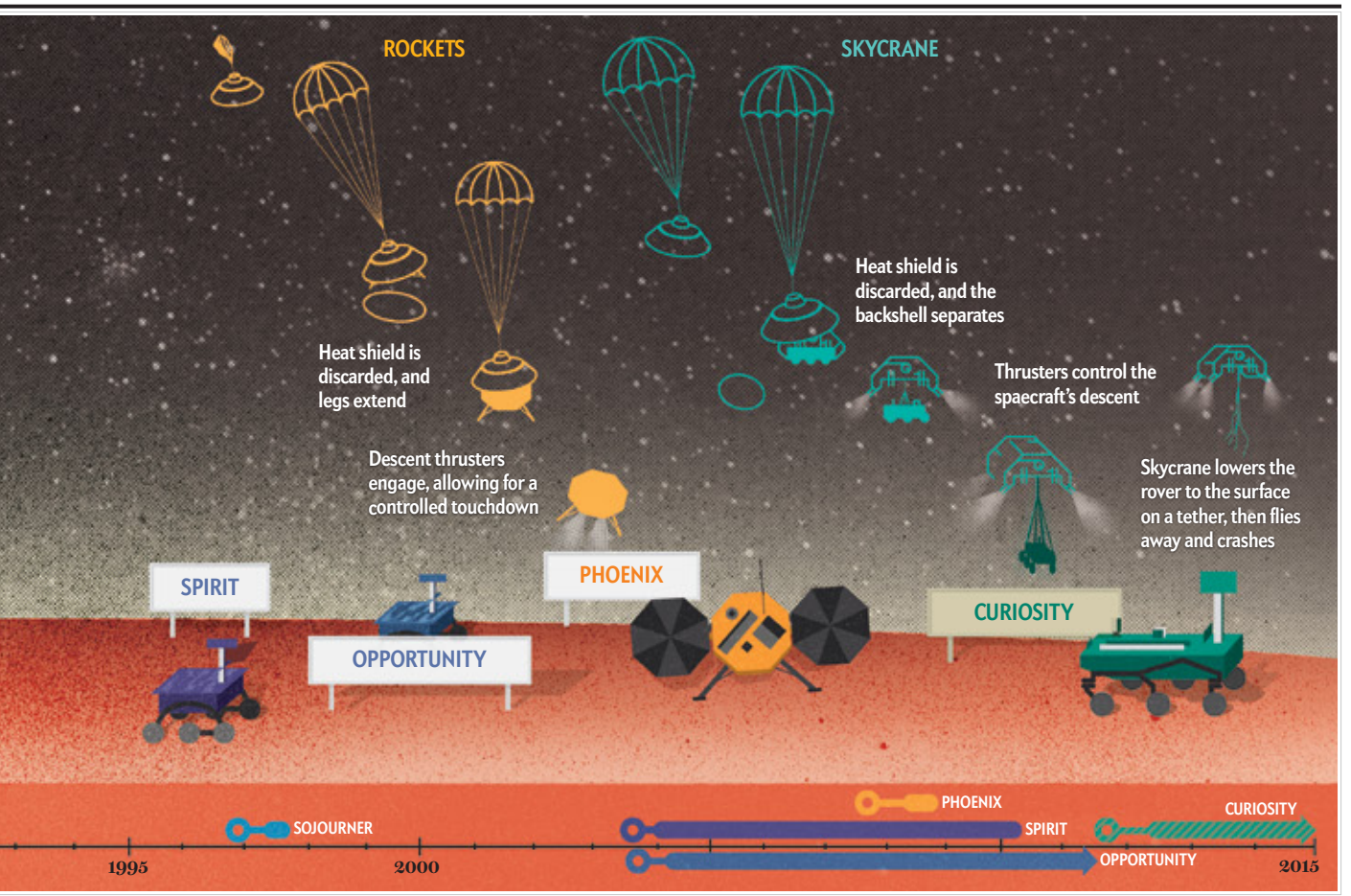
The landing radar failed drop tests, the manufacturer no longer supported it, and launch was only months away.

The launch was over in two minutes, and only the vapor trail was left in the darkened sky. We went back to the control room for a snack and a cup of coffee. I took my muffin and wandered back outside to watch the sunrise. Something unusual was happening in the sky. It took me a few moments to see it. The vapor trail left by the solid rockets was swirling in the stratospheric winds lit by the rising sun. At that moment it struck me: it was the exact form of a phoenix bird. I could make out the beak and wings, with the long tail lashing out behind and whipped forward over the bird's head in the form seen in Chinese paintings. Never have I been so surprised by the shape of a cloud. Could it be a good omen signifying that our voyage to Mars was headed to a successful conclusion? My heart was full, my throat constricted with emotions, the muffin forgotten.

HARROWING LANDING

TEN MONTHS LATER the engineering teams at JPL and Lockheed Martin were preparing for the complex landing maneuvers. The Phoenix spacecraft had traveled 600 million kilometers and was beginning to feel the pull from Mars's gravity. The timing of events was calculated to the second. Odyssey and Mars Reconnaissance Orbiter had already adjusted their orbits and were coordinated to be overhead during the descent to relay Phoenix's signals in real time (delayed by the light travel time to Earth of about 15 minutes). Everything was ready, and the plan was being executed perfectly. So why was I sick with worry?

Landing on Mars is far more complex than landing on the moon or Earth. The spacecraft must transform itself five times. It starts as an interplanetary cruise vehicle. Jettisoning the



cruise stage, it streamlines itself to an entry vehicle able to withstand the heat of friction on entering the atmosphere at nearly 20,000 kilometers per hour. Slowing to 1,500 kph, it releases its parachute from the back shell. In the thin atmosphere, the best the chute can do is decrease the speed to 150 kph, much too fast for a safe landing. One kilometer above the surface, the lander separates from the chute and protective back shell and goes into free fall. Twelve thrusters bring the spacecraft to a terminal speed equivalent to a fast walking pace, and it touches down on the surface, the shock of landing taken up by specially designed landing struts. Finally, the spacecraft must successfully deploy its solar panels and instruments and prepare for its surface mission. All of this happens in seven minutes.

Watching from the control room in Building 230 at JPL, I held my breath when the lander approached one kilometer above the surface. The tension in the room increased as we all remembered the troublesome radar and the loss of Mars Polar Lander. The thrusters had to slow the descent velocity to about 10 kph, reduce any sideward velocity to less than one meter per second, and keep the deck of the lander parallel to the surface. During preparatory meetings, Joe Guinn, our mission manager, had joked that in case a single thruster failed, the other 11 would guide us safely to the crash site. This gallows humor no longer seemed funny; the moment of truth had arrived.

Aeroshell for the Mars Science Laboratory, scheduled to launch this month, includes an atmospheric heat shield larger than those for the *Apollo* capsules.

One of our engineers read out the telemetry from the radar, the distance to the surface in a reverse countdown: 1,000 meters, 800 meters, 600 meters. It was approaching too fast, I thought; we cannot land safely at this speed. Phoenix crossed the 100-meter mark, and it all changed. Now the countdown was 90 meters, 80 meters, 75 meters. We had reached touchdown speed! Soon a signal arrived from the surface, and the room erupted in cheers.

The next two hours, as we waited for Odyssey to orbit Mars and return overhead of our lander, seemed to drag on forever. But at last we confirmed that Phoenix had properly deployed its solar panels and taken its first images. Our first look at the Martian Arctic was magical. Polygonal shapes and tiny rocks stretched to the horizon. After six years of preparation, we were finally able to begin the science mission.

ALMOST FOILED BY CLODS

OUR TEAM OF 35 SCIENTISTS, 50 engineers and 20 students began to work day and night. For efficiency the team worked two shifts on a 24-hour, 40-minute Martian time schedule. The Martian day, or sol, became ours, and our team began to drift away from normal Earth time. We entered a phase of perpetual jet lag.

Our first happy surprise came even before the robot arm dug its first trench. To check the position of the rear footpad, we angled the robotic arm to point under the spacecraft, and its camera revealed that the thrusters had swept aside about five centimeters of dry soil, revealing bright patches: potentially ice [*see illustration on page 49*]. The arm could not reach under the lander to investigate further, but it raised our expectations for what the first trench would unearth.

As the arm began to scoop up dirt, it exposed a bright layer. We watched as scraps of this layer disappeared within three to four sols. Although it appeared to be water ice that sublimated away, we would have to await the results of the Thermal and Evolved-Gas Analyzer (TEGA) instrument to be sure. The other possibility, frozen carbon dioxide, would have vanished more quickly at the ambient temperature of –30 degrees Celsius. Indeed, TEGA later confirmed that the material was water ice. It was the first time subsurface water ice had been confirmed on Mars, validating the Odyssey measurements.

Now that the ice table was exposed, I realized that the entire landscape surrounding the lander (and probably both polar regions) was not the dry, desertlike plain that it seemed but an ice field of unknown depth. To determine whether this ice had ever melted, the lander carried three instruments to analyze the soil: TEGA, which consisted of eight small ovens connected to a mass spectrometer to measure the composition of the gases driven off of a heated sample; the Wet Chemistry Lab (WCL), which added water (brought from Earth) to a soil sample and analyzed the ions that went into solution; and a microscope. We expected synergy between the TEGA and WCL measurements, as they revealed the mineralogy and chemistry of the soil independently.

The highest-priority task was to study the soil chemistry for signs of liquid water, not to mention nutrients and energy

COURTESY OF NASA/JPL-CALTECH

sources for organisms. We also attempted to identify the vertical structure in the soil from the topmost layers to the ice-soil interface. The arm was to gather samples and place them in the analysis ports on the deck of the spacecraft. In principle, the operation was as simple as a child troweling sand into a bucket; however, doing so remotely from 300 million kilometers away proved very challenging. Our operations center in Tucson had a test facility with an identical copy of the robot arm, cameras and sample ports to help us prepare. We tested all commands before sending them to Mars, yet we could not duplicate two aspects of Mars: the winds and the properties of the Martian soil.

The Martian soil appeared crusted, unlike the loose Arizona soils we had practiced with. Consequently, the scoop at the end of the robot arm filled with cloddy, sticky clumps. Screens on the sample ports, intended to keep out pebbles, proved to be very effective in keeping out lumpy soil as well. The arm successfully piled its first sample onto the TEGA inlet screen, but not a single grain sluiced through the port and into the oven for study. The instrument had a device to vibrate the screen, but it took four sols to shake enough material into the oven. In the meantime, any loosely bound water sublimated away.

Over time we learned the best ways to deal with the realities of wind and cloddy soils. We were able to analyze samples at several depths and locations within our digging area. Even so, many samples missed their inlet ports because strong winds blew the soil sideways instead of down into the instrument.

While we were teaching ourselves how best to dig on Mars, the atmospheric sensors were accumulating weather data. The Canadian Space Agency had contributed a lidar that allowed us to measure dust in the atmosphere, as well as the depth of ground fogs and the height of water ice clouds. The instrument also recorded the surface temperature and pressure. In sum, we surveyed the environment from the top of the ice layer to the tropopause, while orbiters scrutinized the region from above to put it all into context.

GOOD ENOUGH FOR ASPARAGUS

AMONG THE GREATEST SURPRISES was the discovery of two unexpected components in the soil: calcium carbonate (at a concentration of 5 percent) and perchlorate (0.5 percent). These compounds are of great importance to our quest for life.

Calcium carbonate forms when atmospheric carbon dioxide dissolves in liquid water, forming carbonic acid. The acid leaches calcium from the soil to form carbonate, which is a very common mineral on Earth. We call it limestone or chalk in natural settings and use it at home under various brand names to buffer our acid stomachs. The WCL measured a pH of 7.7—slightly alkaline and nearly the same as ocean water on Earth, which is also buffered by calcium carbonate.

Planetary scientists have been looking for carbonates on Mars for decades. The multitude of canyons, riverlike features and ancient lake beds leaves little doubt that Mars was once a wet planet, which suggests that the atmosphere used to be much thicker. All the carbon dioxide had to go somewhere, and calcium carbonate rocks were the leading candidates. Phoenix provided the first evidence that they are a component of the soil. Orbiters have since spotted isolated outcrops of calcium carbonate rocks, although other types of carbonates seem more common.

As well as being interesting in its own right, calcium carbonate provides further evidence that the soil at the Phoenix site has been wet in the recent past. It might also explain why the soil was so clumpy and crusty: the mineral can act as a cement.

The alkaline soil at the Phoenix site differs significantly from what other landers have found. Add some more water, increase the air pressure, and the soil could grow asparagus. In contrast, the Opportunity rover has traversed ancient acidic soils rich in sulfate compounds. These speak of a different and older chemical regime hostile to life.

As for the perchlorate, on Earth this chemical is manufactured in the form of ammonium perchlorate for use as the oxidizer in solid rocket fuel—including the nine solid rockets on the Delta II that launched Phoenix into space. In drinking water, perchlorate is considered unsafe at concentrations above 25 parts per billion. Future astronauts beware: the soil is hazardous to health.

What is poison to us, though, is manna to microbes. Natural processes produce a small amount of perchlorate, and it can accumulate in hyperarid deserts, which lack the moisture that readily washes it away in other locations. In the Atacama Desert in Chile, the rains come only once every decade, and perchlorate is able to accumulate. Desert bacteria eke out a living using perchlorates and nitrates as energy sources. Might that also be the case on Mars?

The alkaline soil at the Phoenix site differs significantly from what other landers have found. In fact, the pH of the soil matches that of seawater on Earth.

Recent global climate models have incorporated the orbital dynamics of Mars and included large wobbles in the obliquity (the angle between the orbital plane and the spin axis, currently 25 degrees) to estimate how climate has changed over the past 10 million years. The intensity of solar heating at the poles undergoes dramatic swings from the current cold period to long-term hot spells. Summer temperatures then increase beyond the sublimation point for the ice cap. Ice disappears from the poles and re-forms on high-altitude volcanoes near the equator, producing large glaciers. At that point, the poles become balmy. Perhaps calcium carbonate was formed during these warmer, wetter periods.

One of our observations showed how a microbial ecosystem might be able to operate. The lidar detected snow falling around the spacecraft in the early morning as the Martian summer drew to a close and the sun's rays became ever more oblique. Vapors from evaporating snow could coat dust grains in a process known as adsorption (distinct from absorption). Adsorbed water acts like a very thin layer of liquid. During a warm spell, a layer may thicken to the point where it forms pathways between the dust grains—a microscopic sea where tiny microbes would be totally immersed. The nutrients and oxidants seen by Phoenix would then be available for powering the perchlorate-eating creatures. That said, they would still need the ability to hibernate for several million years to survive the cold, dry epochs.

Perchlorate has another relevant property: If concentrated, it can lower the freezing point of water to –70 degrees C. That means microbes might be able to find a niche on Mars even when the climate turns cold. All in all, the discovery of perchlorate sent a wave of excitement through the Mars community.

IS THE POLE HABITABLE?

THE PRESENCE OF PERCHLORATE may also resolve a 35-year-old mystery. When the Viking soil-analysis experiment heated samples in a tiny oven, it detected the emission of chloromethanes. Viking scientists, unable to understand how such chemicals could be Martian in origin, attributed them to contamination by a cleaning agent used before launch. The same experiment failed to detect any native organic material.

Perchlorate suggests a different interpretation. Researchers at the National Autonomous University of Mexico and their colleagues reran the same experiment with Mars-like soils from the Atacama, with and without small amounts of perchlorate. They reproduced the gaseous output that Viking saw: the perchlorate released its oxygen and combusted the organics, emitting chloromethanes in the process. So a perchlorate-bearing soil could have contained substantial quantities of organics, more than one part per million, and eluded detection by Viking. In support of this interpretation, TEGA found that the soil began to release carbon dioxide as oven temperatures rose above 300 degrees C—just what we would expect if organics in the soil were being oxidized by perchlorate.

All in all, the chances for finding life on Mars have never seemed better. But that was as far as the Phoenix data can take us; it is now up to the Mars Science Laboratory to look for further signs of habitability. The Phoenix results provide only circumstantial evidence, whereas the analysis instrument on the Mars Science Laboratory has the ability to tease out organic signatures in the soil without heating. It does so through a process called derivatization, in which Martian soil is added to a special chemical soup, and any organic molecules are vaporized and detected by a mass spectrometer.

Phoenix had a spectacular a five-month-long mission before the darkness and frigid temperatures of the Martian polar winter closed in. We lost its signal in November 2008. Optimism is an occupational hazard in science research, and as springtime dawned in the northern polar regions of Mars the following year, my colleagues and I held out the hope that the lander would come alive again. It was not to be. The last orbiter image showed Phoenix lying on the bank of a long, riverlike fracture, its solar panels broken, buried in carbon dioxide ice that forms lacework patterns on the bumpy terrain. No longer a scientific outpost, it has become part of the landscape. SA

MORE TO EXPLORE

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SCIENTIFIC AMERICAN ONLINE

For an interactive map and timeline of Mars missions—and to cast your vote in a poll of your favorite Mars-themed movies—visit **ScientificAmerican.com/nov2011/smith**

EXPERIMENTAL ASTROBIOLOGY

THE SMALLEST ASTRONAUTS

Did space rocks seed Earth with life? To test that idea, a Russian probe is about to see whether microbes can survive a round-trip to Mars

By David Warmflash

COULD LIFE ON EARTH HAVE ORIGINATED ON MARS? OVER THE PAST two decades that question has left the pages of science fiction and entered the mainstream of empirical science. Planetary scientists have found that rocks from Mars do make their way to Earth; in fact, we estimate that a ton of Martian material strikes our planet every year. Microorganisms might have come along for the ride. The impacts that launched these rocks into Earth-bound trajectories were violent, high-pressure events, but experiments show that certain species would survive. On passing through Earth's atmosphere, Martian meteoroids are heated only a few millimeters in from their surfaces, so any microbes deeper inside would not burn up [see "Did Life Come from Another World?" by David Warmflash and Benjamin Weiss; SCIENTIFIC AMERICAN, November 2005].

In between takeoff and landing, organisms would need to survive the coast through interplanetary space inside their rocky vessels. Orbital analyses indicate that most Mars meteoroids take thousands or millions of years to get here, but a few (about one in 10 million) arrive within a year or so. Could a bug cling to life for that length of time? The quest for an answer is about to begin.

This month the Russian Federal Space Agency plans to launch the Grunt probe to the Martian moon Phobos. It carries a basketball-size capsule that will collect a scoop of Phobosian soil and return it to Earth in 2014. Within this capsule is a smaller container developed by the Planetary Society, the Living Interplanetary Flight Experiment (LIFE), packed with terrestrial organisms. A soil sample with a mixed population of microorganisms from Israel's Negev Desert lies at the center. Surrounding it are 30 small tubes with 10 species, representing all three domains of Earth's biology: bacteria, archaea and eukaryotes. Five of these species flew on the space shuttle *Endeavour*'s final mission in May as a dress rehearsal.

Our team chose organisms either because they are the terrestrial analogues of putative Martian organisms or because they will let us see just how hardy the hardiest microbes really are.

BACTERIA

One of the bugs is *Deinococcus radiodurans*, famous for being able to survive when its DNA is zapped with enormous doses of radiation. I have been studying the *D. radiodurans* samples that took the *Endeavour* trip and feel quite sure their cousins will survive the trip to Phobos and back. Comparing the robustness of genetically different individuals may give new insights into exactly how these organisms tolerate radiation, desiccation and extreme cold.

Whereas *D. radiodurans* tolerates radiation without changing its cellular form, other bacteria retreat into hardened structures known as endospores. Our experiment includes two of them.

Tardigrade is the cutest of the creatures being sent to Mars. (Magnification: ×500)

PHOTO RESEARCHERS, INC.

David Warmflash, M.D., is an astrobiologist at Portland State University. As science team leader for the Planetary Society's Phobos LIFE project, he is studying the bacteria and archaea that flew on the precursor, Shuttle LIFE, onboard the shuttle *Endeavour* in May 2011.

Bacillus subtilis has a long history as a test species in spaceflight experiments. One of my Phobos LIFE colleagues, Gerda Horneck of the German Aerospace Center, has been sending *B. subtilis* into orbit since the 1960s and demonstrated that its endospores can survive for up to six years in space, coated by only a thin layer of dust, which protects against solar ultraviolet rays. Interplanetary space adds the hazard of charged particle radiation, which is more penetrating.

Our other bacillus, *B. safensis,* was first discovered 10 years ago in the Spacecraft Assembly Facility at the NASA Jet Propulsion Laboratory. Technicians there were sterilizing the Mars Odyssey orbiter to prevent it from contaminating the Red Planet with terrestrial organisms, which might confound future searches for life or, worse, kill any indigenous organisms. Test swabs revealed a species that managed to survive. (Out of the same concerns about contamination, we designed the canister to comply with planetary protection guidelines set by the Committee on Space Research of the International Council for Science.)

ARCHAEA

Resembling bacteria but sharing more of their biochemistry with eukaryotes, archaea are grouped into their own domain. *Methanothermobacter wolfeii* was chosen not because it is especially resilient but because it produces methane. The Martian atmosphere contains traces of this gas, and some scientists have suggested it comes from microbes akin to *M. wolfeii*.

We included *Haloarcula marismortui* for a similar reason. Native to the Dead Sea, it is a salt lover, as any Martian organisms would probably need to be. To avoid freezing, liquid water on the Red Planet must be briny. In fact, one Mars meteorite, Nakhla, shows evidence it was immersed in an ancient brine.

Thriving in volcanically heated ocean sediment, *Pyrococcus furiosus* is no model for life on Mars, but we included it as an experimental control. If our organisms die, we need to be able to tell whether it was the stress of the space environment or the heat of atmospheric reentry that killed them. If *P. furiosus* is the only survivor, we will be able to blame the heat.

EUKARYOTES

Eukaryotes are organisms with nucleated cells, like human cells. We doubt they would have ever made the journey from Mars, but we felt we should study their resilience to space, anyway. One species we included is the commonly studied yeast *Saccharomyces cerevisiae.*

Tiny animals and plants will be flying, too. Tardigrades, known affectionately as water bears, are invertebrates about 1.5 millimeters long with small clawed legs. They are extremely resistant to radiation, temperature extremes and even the space vacuum. Representing plants are seeds of *Arabidopsis thaliana.* Like *B. subtilis, A. thaliana* is a veteran space organism, having traveled twice in *Apollo* capsules.

When the Grunt capsule returns to Earth in 2014, the recovery team will extract the biomodule and send it to ATCC, a biology laboratory in Virginia. Using instruments designed specifically for this purpose, engineers will open the biomodule and distribute samples to participating researchers. Then, at last, we will know whether life can make the leap from planet to planet. SA

MORE TO EXPLORE

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Joshua Knobe is an associate professor in the department of philosophy at Yale University and one of the founders of experimental philosophy. He is known for conceiving the Knobe effect, in which moral judgments exert a surprising impact on people's way of understanding the world.

EXPERIMENTAL PHILOSOPHY

Thought Experiments

Some philosophers today are doing more than thinking deeply. They are also conducting scientific experiments relating to the nature of free will and of good and evil

By Joshua Knobe

THINK OF THE DISCIPLINE OF PHILOSOPHY, AND A CERTAIN SORT OF IMAGE SPRINGS TO MIND. Perhaps you visualize a person sitting comfortably in an armchair, lost in thought, perusing a few old books. Maybe you imagine a field that is scholarly, abstruse by nature and untethered to any grounding in real science. At any rate, you probably do not think of people going out and running experiments.

Yet oddly enough, a cadre of young philosophers have begun doing just that. These "experimental philosophers" argue that inquiry into the most profound questions of philosophy can be informed by actual investigations into why people think and feel as they do. To make progress on these questions, they use all the methods of contemporary cognitive science. They conduct experiments, team up with psychologists and publish in journals that had previously been reserved primarily for scientists. The result has been something of a revolution. Although the movement began only a few years ago, it has already spawned hundreds of papers, a steady stream of surprising results and some very strong opinions on every side.

All of this might at first seem deeply peculiar—almost as though philosophers have stopped doing real philosophy and started switching over to something else entirely. Yet perhaps this approach isn't actually quite as odd as it might initially appear. In a typical research program, scientists work with certain instruments (telescopes in astronomy, microscopes in biology, and so on). Usually they don't think much about the instruments themselves; they simply use them to get at some independently existing reality. Still, now and then researchers get puzzled or confused by the information coming from their instruments. Maybe this information seems wildly implausible, or goes against established bodies of theory, or is internally contradictory. In such cases, it often proves helpful to turn away from the reality one is primarily trying to study and to look in detail

IN BRIEF

The classic image of the philosopher pictures an ethereal type who is lost in thought and detached from the pedestrian concerns of everyday realities. **A new breed** of thinker is now bringing to bear the cognitive sciences to probe why people perceive the world in the particular way that they do. **The tenets** of experimental philosophy can elucidate whether free will really exists and whether morality is just a relative construct.

STYLING BY WENDY SCHELAH

Photograph by Zachary Zavislak

at the instruments themselves. One might even find that the best way to resolve a question in astronomy is to start engaging in a scientific study of telescopes.

Now, philosophers do not make much use of telescopes or microscopes. We rely almost entirely on one particular instrument: the human mind, which produces the ideas that drive our profession. Still, the same basic principle applies. Typically we do not worry too much about the workings of our own minds and simply use them to get at an independent reality. Sometimes this approach fails, though. Sometimes our mind seems to pull us in two directions, almost as if two different voices within us are giving opposite answers to the same question. In situations like these, it can be helpful to explore the mind itself and to look scientifically at the sources of our own and others' philosophical intuitions.

This is where experimental philosophy comes in. The key idea is that if we can get a better understanding of the psychology behind philosophical intuitions, we can have a better sense of which intuitions are worthy of our trust and which we should dismiss as unreliable or misleading.

This work, we hope, will give us a better understanding of people's beliefs about the great philosophical issues. How is it that individuals come to believe in free will? Do they see their own moral claims as objective truths? The findings could ultimately have practical implications in jurisprudence, ethics and other fields.

FREE WILL, EXPERIMENTAL-STYLE

IMAGINE WITNESSING A MURDER. As you look at the scene in front of you, it may initially seem obvious that the murderer is morally responsible for what he has done and absolutely deserving of punishment. Now suppose you pause to think the matter over philosophically. The murderer's action was presumably caused by certain mental states he had, and these mental states were probably caused by yet earlier events … so that ultimately his act might just be the final step in a chain that could be traced back to certain facts about his genes and environment. Yet if that sequence shaped him, can he ever really be morally responsible for the things he has done? Some philosophers say yes, others say no, and the debate between these two positions has gone back and forth endlessly. This is the age-old problem of free will.

Experimental philosopher Shaun Nichols of the University of Arizona and I thought that the conflict surrounding this problem might have its roots in a tension between two forms of human cognition. Perhaps our capacity for abstract theoretical reflection leads us to think in one way, whereas our more immediate emotional responses pull us in exactly the opposite direction. One impulse tells us: "Well, if you think about it rationally, his behavior is just one step in a complex causal chain, and he can therefore never really be truly free or responsible." Then another one intrudes: "Wait! This guy is a murderer! He simply has to be to blame for what he has done."

In conducting an experiment, Nichols and I started out by asking participants about a fictitious universe ("Universe A") in which everything anyone did was completely determined by a chain of causation stretching back into the past.

Each participant was then randomly assigned to one of two conditions. Those in one condition were asked a question designed to trigger abstract theoretical reflection:

In Universe A, *is it possible for people to be fully morally responsible for their actions?*

Participants in the other condition were given a highly concrete, even lurid story designed to elicit a more emotional response:

In Universe A, *a man named Bill is attracted to his secretary and decides that the only way to be with her is to kill his wife and three children. He knows that it is impossible to escape from his house in the event of a fire. Before leaving on a business trip, he sets up a device that burns down the house and kills his family. Is Bill fully morally responsible for killing his wife and children?*

Those who got the abstract theoretical question tended to say no—no one can be morally responsible in a deterministic universe—whereas those who got the second, more concrete question tended to take exactly the opposite view, saying Bill did indeed bear responsibility for his actions. In other words, people claim in the abstract that no one can be morally responsible in a deterministic universe, but when they are confronted with a story about a specific individual engaged in some dastardly deed, they are perfectly willing to say he is morally responsible regardless of what kind of universe he happens to live in.

Although this first study was relatively small, conducted on a few dozen American undergraduates, the next few years saw a number of attempts to explore these phenomena more rigorously. One such experiment used a much larger sample (with more than 1,000 participants); another looked at intuitions about the abstract case across a number of different cultures (India, Hong Kong, Colombia and the U.S.). Each time the original findings continued to emerge. At that point, it did seem that we had latched onto some kind of genuine effect, yet questions remained about why exactly this effect was arising. Did the effect actually reflect a difference between abstract and concrete thinking? To further explore the issue, we needed studies that used somewhat different methods.

One of the most striking and elegant tests was conducted by experimental philosopher Christine Weigel of Utah Valley University. All participants were told to imagine hearing a philosophy lecture about the problem of free will. The lecture they were asked to imagine explained the problem in a general way and then concluded with the very example described earlier: a man in a deterministic universe who kills his own wife and children. But Weigel then introduced an incredibly subtle manipulation. Some participants were asked to imagine that the lecture was happening "in a few years," whereas others were asked to imagine that the lecture was happening "in a few days."

This manipulation might not seem to have anything much to do with free will, but it does have a lot to do with human cognition. A whole series of experimental studies have shown that imagining an event at a more distant time leads people to employ a different type of cognitive process: more abstract, theoretical and high level. In other words, the story about the more distant time should trigger a more reflective sort of process ("'Well, if you think about it rationally...."), and the story about the closer time should trigger individuals' more concrete intuitions ("Wait! This guy is a murderer!"). Sure enough, Weigel found that her manipulation was changing people's intuitions. Those who were told to imagine a more distant event ended up being less likely to say that human beings could be morally responsible even in a deterministic universe.

It is beginning to seem increasingly plausible that people's sense of perplexity and inner conflict regarding the problem of free will does indeed derive from a tension between their more ab-

stract theoretical judgments and their more concrete emotional responses. Moreover, the situations they find themselves in at a given moment markedly influence the moral stances they adopt.

Of course, the mere fact that this hypothesis has received support in a few initial studies does not prove that it is true. Experimental philosopher Eddy Nahmias of Georgia State University has proposed an important rival hypothesis that does not involve any conflict between reason and emotion, and it is widely agreed that the evidence available now from these experiments is not sufficient to resolve all the major questions. At the very least, though, what we have here is definitely a start. Although a great deal still remains to be done, we now have the beginnings of an experimental research program on the psychological roots of people's understanding of free will.

Investigations into why people think and feel the way they do can provide valuable insight into which philosophical ideas are truly worth embracing.

IS MORALITY RELATIVE?

I HAVE BEEN FOCUSING thus far on issues that may seem a little bit abstruse or academic, but experimental philosophy can also help illuminate the questions at the heart of contemporary controversies about morality.

Imagine that Sven and Xiex are from two different cultures. Sven says, "Hitting other people is morally bad," whereas Xiex says, "Hitting other people is perfectly fine—just the right way to prove one's strength and valor." We now face a difficult question: Given that Sven and Xiex have opposite opinions, does one of them have to be wrong? Or could it be that there is no single right answer here, so that each of them can be right relative to his own culture's system of values?

Of all the complex theoretical questions discussed by philosophers, this one has been among the most polarizing within Western culture as a whole. Campus radicals of various stripes often suggest that there is no single moral truth and that morality is always fundamentally relative; more conservative thinkers often insist on the existence of objective moral truths. Pope Benedict XVI himself recently waded into the debate, declaring that moral relativism leads "to moral or intellectual confusion, to a lowering of standards, to a loss of self-respect, and even to despair."

In an attempt to get at the psychological roots of this controversy, psychologist Edward T. Cokely of Michigan Technological University and philosopher Adam Feltz of Schreiner University gave study participants a story about people who hold opposite views on a moral question. Subjects were then asked whether one disputant had to be wrong (the antirelativist answer) or whether there might be no single correct position (the relativist answer). Cokely and Feltz's study also included an interesting twist.

They gave each participant a standard measure of the personality trait "openness to experience," and they were able to determine which participants were more open to experience and which were more closed. The results showed a significant correlation: the higher a participant was in openness to experience, the more likely that participant was to endorse the relativist answer.

These studies suggest a hypothesis about the roots of relativism. Perhaps the pull people sometimes feel toward moral relativism is related to a kind of openness. When confronted with other perspectives and other possible ways of life, they feel drawn to relativism to the extent that they open themselves up to these other possibilities and enter into them imaginatively.

In an innovative test of this hypothesis, psychologists Geoffrey Goodwin of the University of Pennsylvania and John Darley of Princeton University measured participants' ways of thinking by giving each of them a logic puzzle that involved configuring blocks in a certain way. Although the problem seemed straightforward on the surface, there was actually a trick: one could only get the right answer by looking at the problem from multiple perspectives. The key research question then was about the relation between people's abilities in solving this problem and their intuitions about relativism. Surprisingly enough, the researchers again found a significant correlation. Those who got the problem right were especially likely to offer relativist answers.

Thus, we are beginning to see a kind of convergence. We have a series of different studies, conducted by different researchers, using quite different methods, and yet they all seem to be pointing toward the same basic conclusion: people feel drawn to relativism to the extent that they can open themselves to other possible perspectives. This result may help give us some much needed insight into the roots of one of the most enduring philosophical controversies of our time.

SHOULD WE BURN THE ARMCHAIR?

SUPPOSE NOW, if only for the sake of argument, that experimental philosophy continues to make progress. Imagine that all our empirical questions are resolved and that we eventually arrive at an accurate understanding of the cognitive processes underlying people's philosophical views. Even then, it may seem that we would not have fully addressed the original question at the heart of the philosophical debate—namely, whether these views are actually right or wrong. This latter question, one might think, just isn't even the sort of thing one could potentially answer by doing experiments. Sooner or later someone is going to have to get back into that armchair and reflect hard on the philosophical issues themselves.

Taken in itself, this point is eminently fair and reasonable, and any philosopher should be happy to accept it. But it would be a big mistake to treat it as some devastating objection to the whole project of experimental philosophy. No one is suggesting that philosophers should abandon other forms of thought and spend their time running experiments; rather experimental work should be part of a larger philosophical inquiry. Experimental philosophy is just adding a tool to the philosopher's toolbox. As we are sitting in our armchairs wrestling through the tensions among our different beliefs, it can sometimes be helpful, and occasionally indispensable, to have a better understanding of the cognitive processes that gave rise to those beliefs. SA

MORE TO EXPLORE

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SCIENTIFIC AMERICAN ONLINE

Read about the Knobe effect at ScientificAmerican/nov2011/knobe

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SUSTAINABILITY

CAN WE FEED THE WORLD & SUSTAIN THE PLANET?

A five-step global plan could double food production by 2050 while greatly reducing environmental damage

By Jonathan A. Foley

KEVIN VAN AELST

IGHT NOW ABOUT ONE BILLION PEOPLE SUFFER FROM CHRONIC HUNGER. THE WORLD'S farmers grow enough food to feed them, but it is not properly distributed and, even if it were, many cannot afford it, because prices are escalating.

But another challenge looms.

By 2050 the world's population will increase by two billion or three billion, which will likely double the demand for food, according to several studies. Demand will also rise because many more people will have higher incomes, which means they will eat more, especially meat. Increasing use of cropland for biofuels will put additional demands on our farms. So even if we solve today's problems of poverty and access—a daunting task—we will also have to produce twice as much to guarantee adequate supply worldwide.

And that's not all.

By clearing tropical forests, farming marginal lands, and intensifying industrial farming in sensitive landscapes and watersheds, humankind has made agriculture the planet's dominant environmental threat. Agriculture already consumes a large percentage of the earth's land surface and is destroying habitat, using up freshwater, polluting rivers and oceans, and emitting greenhouse gases more extensively than almost any other human activity. To guarantee the globe's long-term health, we must dramatically reduce agriculture's adverse impacts.

The world's food system faces three incredible, interwoven challenges. It must guarantee that all seven billion people alive today are adequately fed; it must double food production in the next 40 years; and it must achieve both goals while becoming truly environmentally sustainable.

Could these simultaneous goals possibly be met? An international team of experts, which I coordinated, has settled on five steps that, if pursued together, could raise by more than 100 percent the food available for human consumption globally, while significantly lessening greenhouse gas emissions, biodiversity losses, water use and water pollution. Tackling the triple challenge will be one of the most important tests humanity has ever faced. It is fair to say that our response will determine the fate of our civilization.

BUMPING UP AGAINST BARRIERS

AT FIRST BLUSH, the way to feed more people would seem clear: grow more food, by expanding farmland and improving yield—the amount of crops harvested per hectare. Unfortunately, the world is running into significant barriers on both counts.

Society already farms roughly 38 percent of the earth's land surface, not counting Greenland or Antarctica. Agriculture is by far the biggest human use of land on the planet; nothing else comes close. And most of that 38 percent covers the *best* farmland. Much of the remainder is covered by deserts, mountains, tundra, ice, cities, parks and other unsuitable growing areas. The few remaining frontiers are mainly in tropical forests and savannas, which are vital to the stability of the globe, especially as stores of carbon and biodiversity. Expanding into those areas is not a good idea, yet over the past 20 years five million to 10 million hectares of cropland a year have been created, with a significant portion of that amount in the tropics. These additions enlarged the net area of cultivated land by only 3 percent, however, because of farmland losses caused by urban development and other forces, particularly in temperate zones.

Improving yield also sounds enticing. Yet our research team found that average global crop yield increased by about 20 percent in the past 20 years—far less than what is typically reported. That improvement is significant, but the rate is nowhere near enough to double food production by midcentury. Whereas yields of some crops improved substantially, others saw little gain and a few even declined.

Feeding more people would be easier if all the food we grew went into human hands. But only 60 percent of the world's crops are meant for people: mostly grains, followed by pulses (beans, lentils), oil plants, vegetables and fruits. Another 35 percent is used for animal feed, and the final 5 percent goes to biofuels and other industrial products. Meat is the biggest issue here. Even with the most efficient meat and dairy systems, feeding crops to animals reduces the world's potential food supply. Typically grain-fed cattle operations use 30 kilograms of grain to make one kilogram of edible, boneless beef. Chicken and pork are more efficient, and grass-fed beef converts nonfood material into protein. No matter how you slice it, though, grain-fed meat production systems are a drain on the global food supply.

Another deterrent to growing more food is damage to the en-

IN BRIEF

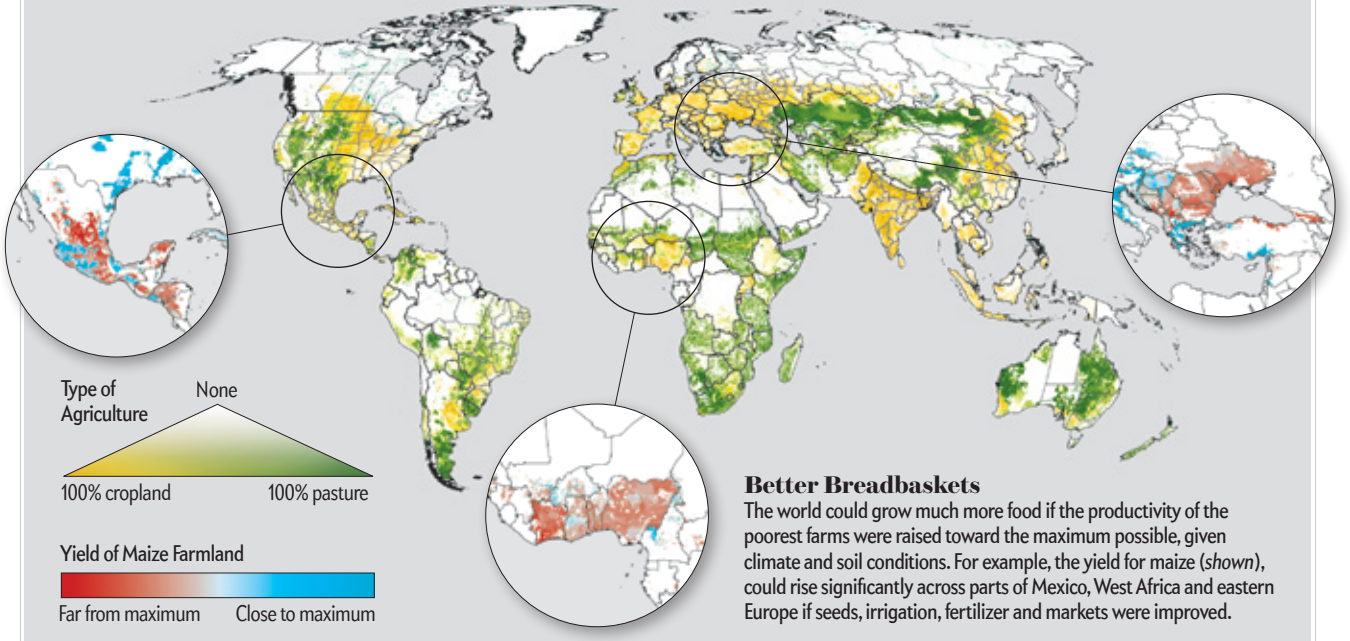
The world must solve three food problems simultaneously: end hunger, double food production by 2050, and do both while drastically reducing agriculture's damage to the environment.

Five solutions, pursued together, can achieve these goals: stop agriculture from consuming more tropical land, boost the productivity of farms that have the lowest yields, raise the efficiency of water and fertilizer use worldwide, reduce per capita meat consumption and reduce waste in food production and distribution.

A system for certifying foods based on how well each one delivers nutrition and food security and limits environmental and social costs would help the public choose products that push agriculture in a more sustainable direction.

Farming Hits the Wall, but Not the Ceiling

Humankind now farms 38 percent of the earth's ice-free land. Crops take up one third of that area; pastures and rangelands for livestock cover the rest. Little room exists for expansion because most of the remaining land is deserts, mountains, tundra or urban. Still, farms in many existing areas could be more productive (*insets*).



Better Breadbaskets
The world could grow much more food if the productivity of the poorest farms were raised toward the maximum possible, given climate and soil conditions. For example, the yield for maize (*shown*), could rise significantly across parts of Mexico, West Africa and eastern Europe if seeds, irrigation, fertilizer and markets were improved.

COURTESY OF JAMES GERBER *Institute on the Environment, University of Minnesota (maps)*

vironment, which is already extensive. Only our use of energy, with its profound impacts on climate and ocean acidification, rivals the sheer magnitude of agriculture's environmental impacts. Our research team estimates that agriculture has already cleared or radically transformed 70 percent of the world's prehistoric grasslands, 50 percent of the savannas, 45 percent of the temperate deciduous forests and 25 percent of the tropical forests. Since the last ice age, nothing has disrupted ecosystems more. Agriculture's physical footprint is nearly 60 times that of the world's pavements and buildings.

Freshwater is another casualty. Humans use an astounding 4,000 cubic kilometers of water per year, mostly withdrawn from rivers and aquifers. Irrigation accounts for 70 percent of the draw. If we count only consumptive water use—water that is used and not returned to the watershed—irrigation climbs to 80 or 90 percent of the total. As a result, many large rivers, such as the Colorado, have diminished flows, some have dried up altogether, and many places have rapidly declining water tables, including regions of the U.S. and India.

Water is not only disappearing, it is being contaminated. Fertilizers, herbicides and pesticides are being spread at incredible levels and are found in nearly every ecosystem. The flows of nitrogen and phosphorus through the environment have more than doubled since 1960, causing widespread water pollution and enormous hypoxic "dead zones" at the mouths of many of the world's major rivers. Ironically, fertilizer runoff from farmland—in the name of growing more food—compromises another crucial source of nutrition: coastal fishing grounds. Fertilizer certainly has been a key ingredient of the green revolution that has helped feed the world, but when nearly half the fertilizer we apply runs off rather than nourishes crops, we clearly can do better.

Agriculture is also the largest single source of greenhouse gas emissions from society, collectively accounting for about 35 percent of the carbon dioxide, methane and nitrous oxide we release. That is more than the emissions from worldwide transportation (including all cars, trucks and planes) or electricity generation. The energy used to grow, process and transport food is a concern, but the vast majority of emissions comes from tropical deforestation, methane released from animals and rice paddies, and nitrous oxide from overfertilized soils.

FIVE SOLUTIONS

MODERN AGRICULTURE has been an incredibly positive force in the world, but we can no longer ignore its dwindling ability to expand or the mounting environmental harm it imposes. Previous approaches to solving food and environmental issues were often at odds. We could boost food production by clearing more land or using more water and chemicals but only at a cost to the environment. Or we could restore ecosystems by taking farmland out of cultivation but only by reducing food production. This either-or approach is no longer acceptable. We need truly integrated solutions.

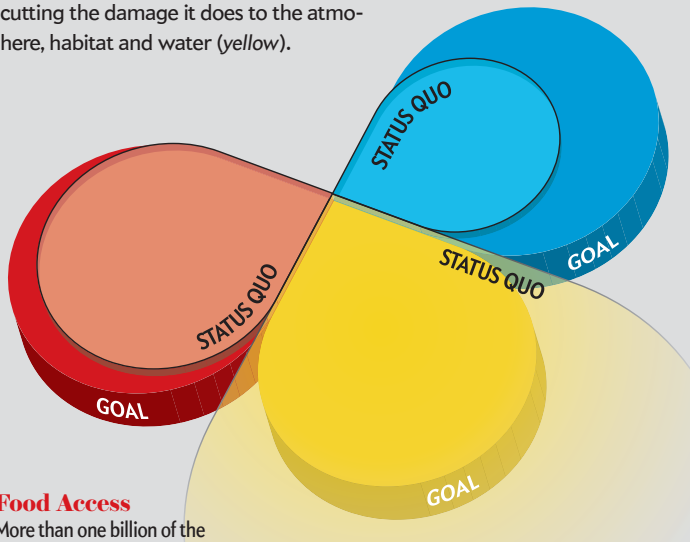
After many months of research and deliberation—based on analysis of newly generated global agricultural and environmental data—our international team has settled on a five-point plan for dealing with food and environmental challenges together.

Output Expands, Harm Contracts

To feed the world without harming the planet, agriculture will have to produce much more food (*blue*) and find better ways to distribute it (*red*), while significantly cutting the damage it does to the atmosphere, habitat and water (*yellow*).

Food Production

By 2050 global population will be two billion to three billion greater, and a larger proportion of people will have higher incomes, so they will consume more per person. Farmers will need to grow twice as much as they do today.



Food Access

More than one billion of the earth's seven billion people suffer from chronic hunger. Poverty and poor distribution of food must be overcome to provide adequate calories for everyone.

Environmental Damage

To reduce harm, agriculture must stop expanding into tropical forests, raise the productivity of underperforming farmland (which could boost production 50 to 60 percent), use water and fertilizer far more efficiently, and prevent soil degradation.

Stop expanding agriculture's footprint. Our first recommendation is to slow and ultimately stop the expansion of agriculture, particularly into tropical forests and savannas. The demise of these ecosystems has far-reaching impacts on the environment, especially through lost biodiversity and increased carbon dioxide emissions (from clearing land).

Slowing deforestation would dramatically reduce environmental damage while imposing only minor constraints on global food production. The resulting dip in farm capacity could be offset by reducing the displacement of more productive croplands by urbanization, degradation and abandonment.

Many proposals have been made to reduce deforestation. One of the most promising is the Reducing Emissions from Deforestation and Degradation (REDD) mechanism. Under REDD, rich nations pay tropical nations to protect their rain forests, in exchange for carbon credits. Other mechanisms include developing certification standards for agricultural products so that supply chains can be assured that crops were not grown on lands created by deforestation. Also, better biofuel policy that relies on nonfood crops such as switchgrass instead of food crops could make vital farmland newly available.

Close the world's yield gaps. To double global food production without expanding agriculture's footprint, we must significantly improve yields of existing farmlands. Two options exist: We can boost the productivity of our best farms—raising their "yield ceiling" through improved crop genetics and management. Or we can improve the yields of the world's least productive farms—closing the "yield gap" between a farm's current yield and its higher potential yield. The second option provides the largest and most immediate gain—especially in regions where hunger is most acute.

Our research team has analyzed global patterns of crop yields and found that much of the world has a significant yield gap. In particular, yields could increase substantially across many parts of Africa, Central America and eastern Europe. In these regions, better seeds, more effective fertilizer application and efficient irrigation could produce much more food on the same amount of land. Our analysis suggests that closing the yield gap for the world's top 16 crops could increase total food production by 50 to 60 percent, with little environmental damage.

Reducing yield gaps in the least productive agricultural lands may often require some additional fertilizer and water. Care will have to be taken to avoid unbridled irrigation and chemical use. Many other techniques can improve yield. "Reduced tillage" planting techniques disturb less soil, preventing erosion. Cover crops planted between food-crop seasons reduce weeds and add nutrients and nitrogen to the soil when plowed under. Lessons from organic and agroecological systems can also be adopted, such as leaving crop residues on fields so that they decompose into nutrients. To close the world's yield gaps, we also have to overcome serious economic and social challenges, including better distribution of fertilizer and seed varieties to farms in impoverished regions and improving access to global markets for many regions.

Use resources much more efficiently. To reduce the environmental impacts of agriculture, low- and high-yield regions alike must practice agriculture with vastly greater efficiency: far more crop output per unit of water, fertilizer and energy.

On average, it takes about one liter of irrigation water to grow one calorie of food, although some places use much more. Our analysis finds that farms can significantly curb water use without much reduction in food production, especially in dry climates. Primary strategies include drip irrigation (where water is applied directly to the plant's base and not wastefully sprayed into the air); mulching (covering the soil with organic matter to retain moisture); and reducing water lost from irrigation systems (by lessening evaporation from canals and reservoirs).

With fertilizers, we face a kind of Goldilocks problem. Some places have too few nutrients and therefore poor crop production, whereas others have too much, leading to pollution. Almost

Graphic by Jen Christiansen

no one uses fertilizers "just right." Our analysis shows hotspots on the planet—particularly in China, northern India, the central U.S. and western Europe—where farmers could substantially reduce fertilizer use with little or no impact on food production. Amazingly, only 10 percent of the world's cropland generates 30 to 40 percent of agriculture's fertilizer pollution.

Among the actions that can fix this excess are policy and economic incentives, such as payments to farmers for watershed stewardship and protection, for reducing excessive fertilizer use, for improving manure management (especially manure storage, so that less runs off into the watershed during a storm), for capturing excess nutrients through recycling, and for instituting other conservation practices. In addition, restoring wetlands will enhance their capacity to act as a natural sponge to filter out nutrients in runoff.

Here again reduced tillage can help nourish the soil, as can precision agriculture (applying fertilizer and water only when and where they are needed and most effective) and organic farming techniques.

Shift diets away from meat. We can dramatically increase global food availability and environmental sustainability by using more of our crops to feed people directly and less to fatten livestock.

Globally, humans could net up to three quadrillion additional calories every year—a 50 percent increase from our current supply—by switching to all-plant diets. Naturally, our current diets and uses of crops have many economic and social benefits, and our preferences are unlikely to change completely. Still, even small shifts in diet, say, from grain-fed beef to poultry, pork or pasture-fed beef, can pay off handsomely.

Reduce food waste. A final, obvious but often neglected recommendation is to reduce waste in the food system. Roughly 30 percent of the food produced on the planet is discarded, lost, spoiled or consumed by pests.

In rich countries, much of the waste takes place at the consumer end of the system, in restaurants and trash cans. Simple changes in our daily consumption patterns—reducing oversize portions, food thrown in the garbage, and the number of takeout and restaurant meals—could significantly trim losses, as well as our expanding waistlines. In poorer countries, the losses are similar in size but occur at the producer end, in the form of failed crops, stockpiles ruined by pests, or food that is never delivered because of bad infrastructure and markets. Improved storage, refrigeration and distribution systems can cut waste appreciably. Moreover, better market tools can connect people who have crops to those who need them, such as cell-phone systems in Africa that link suppliers, traders and purchasers.

Although completely eliminating waste from farm to fork is not realistic, even small steps would be extremely beneficial. Targeted efforts—especially reducing waste of the most resource-intensive foods such as meat and dairy—could make a big difference.

MOVING TOWARD A NETWORKED FOOD SYSTEM

IN PRINCIPLE, our five-point strategy can address many food security and environmental challenges. Together the steps could increase the world's food availability by 100 to 180 percent, while significantly lowering greenhouse gas emissions, biodiversity losses, water use and water pollution.

It is important to emphasize that all five points (and perhaps more) must be pursued together. No single strategy is sufficient to solve all our problems. Think silver buckshot, not a silver bullet. We have tremendous successes from the green revolution and industrial-scale agriculture to build on, along with innovations in organic farming and local food systems. Let's take the best ideas and incorporate them into a new approach—a sustainable food system that focuses on nutritional, social and environmental performance, to bring responsible food production to scale.

We can configure this next-generation system as a network of local agricultural systems that are sensitive to nearby climate, water resources, ecosystems and culture and that are connected through efficient means of global trade and transport. Such a system could be resilient and also pay farmers a living wage.

One device that would help foster this new food system would be the equivalent of the Leadership in Energy and Environmental Design program now in place for constructing new commercial buildings sustainably. This LEED program awards increasingly higher levels of certification based on points that are accumulated by incorporating any of a wide range of green options, from solar power and efficient lighting to recycled building materials and low construction waste.

For sustainable agriculture, foods would be awarded points based on how well they deliver nutrition, food security and other public benefits, minus their environmental and social costs. This certification would help us get beyond current food labels such as "local" and "organic," which really do not tell us much about what we are eating. Instead we can look at the whole performance of our food—across nutritional, social and environmental dimensions—and weigh the costs and benefits of different farming approaches.

Imagine the possibilities: sustainable citrus and coffee from the tropics, connected to sustainable cereals from the temperate zone, supplemented by locally grown greens and root vegetables, all grown under transparent, performance-based standards. Use your smartphone and the latest sustainable food app, and you will learn where your food came from, who grew it, how it was grown, and how it ranks against various social, nutritional and environmental criteria. And when you find food that works, you can tweet about it to your social network of farmers and foodies.

The principles and practices of our different agricultural systems—from large-scale commercial to local and organic—provide the foundation for grappling with the world's food security and environmental needs. Feeding nine billion people in a truly sustainable way will be one of the greatest challenges our civilization has had to confront. It will require the imagination, determination and hard work of countless people from all over the world. There is no time to lose. SA

MORE TO EXPLORE

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GEOLOGY

SLEEPING GIANT

The volcano beneath this calm-looking lake has grown restive, inspiring a rare collaboration between Chinese and Korean scientists

By Sid Perkins

THE SERENE WATERS OF SKY POND, ONE OF THE MOST POPULAR tourist attractions in northeastern Asia, belie the fact that it is nestled inside the crater of one of the region's most dangerous volcanoes—a peak known as Changbai Mountain to the Chinese and Mount Paektu to Koreans. That 2,744-meter-tall volcano, which straddles the border between China and North Korea, last erupted in 1903 but has displayed signs of awakening in recent years.

The lake is the source of three Asian rivers that, during an eruption, could serve as conduits for lahars—devastating blends of hot ash, mud and water that have the consistency of wet cement. A major eruption could send such flows racing down the volcano's slopes, threatening hundreds of thousands of people.

The massive earthquake and tsunami that devastated Japan in March spurred regional scientists into action. This past August teams of geologists from China and North and South Korea, in an unusual collaboration, carried out field studies on the peak and planned to hold a workshop this fall on forecasting and preparing for a natural disaster. Tapping into a seismic network installed on the Chinese side of the mountain in 1999 as well as readings from GPS equipment on the volcano's slopes, researchers have detected a series of shallow earthquakes as well as a gradual rise in the peak since 2002, which investigators believe is being caused by the movement of magma into a chamber below the volcano. The scientists think the magma is coming from deep inside the earth's mantle, which may make an eruption more likely.

Despite the international collaboration, data sharing to date has been sparse, says Sung-hyo Yun of Pusan National University in South Korea. "So far the work has not been easy," he notes. SA

HENRY WESTHEIM PHOTOGRAPHY/ALAMY

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A new breed of genetically modified mosquitoes carries a gene that cripples its own offspring. They could crush native mosquito populations and block the spread of disease. And they are already in the air—though that's been a secret *By Bijal P. Trivedi*

Buzz kill: The *Aedes aegypti* mosquito is the primary carrier of dengue fever.

Photograph by David Liittschwager

Bijal P. Trivedi is an award-winning writer who focuses on biology, the environment and medicine. She studied molecular biology and biochemistry at Oberlin College and at the University of California, Los Angeles.

OUTSIDE TAPACHULA, CHIAPAS, MEXICO—10 MILES FROM GUATEMALA.

To reach the cages, we follow the main highway out of town, driving past soy, cocoa, banana and lustrous dark-green mango plantations thriving in the rich volcanic soil. Past the tiny village of Rio Florido the road degenerates into an undulating dirt tract. We bump along on waves of baked mud until we reach a security checkpoint, guard at the ready. A sign posted on the barbed wire–enclosed compound pictures a mosquito flanked by a man and woman: *Estos mosquitos genéticamente modificados requieren un manejo especial,* it reads. *We play by the rules.*

Inside, cashew trees frame a cluster of gauzy mesh cages perched on a platform. The cages hold thousands of *Aedes aegypti* mosquitoes—the local species, smaller and quieter than the typical buzzing specimens found in the U.S. At 7 A.M., the scene looks ethereal: rays of sunlight filter through layers of mesh creating a glowing, yellow hue. Inside the cages, however, genetically modified mosquitoes are waging a death match against the locals, an attempted genocide-by-mating that has the potential to wipe out dengue fever, one of the world's most troublesome, aggressive diseases.

Throughout a swath of subtropical and tropical countries, four closely related dengue viruses infect about 100 million people annually, causing a spectrum of illness—from flu-like aches to internal hemorrhaging, shock and death. No vaccine or cure exists. As with other mosquito-borne diseases, the primary public health strategy is to prevent people from being bitten. To that end, authorities attempt to rid neighborhoods of standing water where the insects breed, spray with insecticides, and distribute bed nets and other low-tech mosquito blockers. They pursue containment, not conquest.

Anthony James, however, is mounting an offensive. James, a molecular biologist at the University of California, Irvine, and his colleagues have added genes to *A. aegypti* that block the development of flight muscles in females. When a genetically modified male mosquito mates with a wild female, he passes his engineered genes to the offspring. The females—the biters—don't survive long. When they emerge from the pupal stage, they sit motionless on the water. They won't fly, mate or spread disease. The male progeny, in contrast, will live to spread their filicidal seed. In time, the absence of female offspring should lead to a population crash, which James's collaborator has already demonstrated in the controlled environment of an indoor laboratory in Colorado. Now he has brought his bugs south.

The technology marks the first time scientists have genetically engineered an organism to specifically wipe out a native population to block disease transmission. If the modified mosquitoes

IN BRIEF

Scientists have genetically engineered mosquitoes with a self-destruct mechanism, an advance that could slow the spread of mosquito-borne diseases.

One team of scientists has been conducting tests of the mosquitoes in cages in southern Mexico. Another has been releasing mosquitoes out into the wild.

The intentional release of genetically modified insects has sparked international controversy, especially because the first releases were conducted in secret.

triumph, then releasing them in dengue-endemic zones worldwide could prevent tens of millions of people from suffering. Yet opponents of the plan warn of unintended consequences—even if mosquitoes are the intended victims.

Researchers also struggle with how to test their creations. No international laws or agencies exist to police trials of new transgenic organisms. For the most part, scientists and biotech companies can do what they want—even performing uncontrolled releases of test organisms in developing countries, neither warning the residents that their backyards are about to become a de facto biocolonialist field laboratory nor gaining their consent.

James has spent years attempting to play it straight. He has worked with community leaders in Tapachula, acquiring property through the traditional land-sharing program and building a secure test facility—all arduous, time-consuming, careful work. But he is not the only researcher testing modified mosquitoes outside the lab. James's colleague Luke Alphey, founder of the U.K.-based biotechnology company Oxitec, has quietly pursued a more aggressive test strategy. In 2009 and 2010 his organization took advantage of the minimal regulations in the Caribbean's Grand Cayman island to release millions of genetically modified mosquitoes into the wild. James first learned of the experiments when Alphey described them publicly at a conference in Atlanta in 2010—14 months after the fact. Since then, Oxitec has continued the trials, releasing modified mosquitoes in Malaysia and Brazil.

Deadly mates: Inside the cages in southern Mexico, scientists introduce genetically modified mosquitoes into a group of locals. The intruders should crash the native population.

COURTESY OF BIJAL P. TRIVEDI

Experts fear Oxitec's actions could trigger a backlash against all genetically modified insects reminiscent of Europe's rejection of GM crops, a move that could snuff out the technology before scientists can fully understand both its promise and its potential consequences.

That would be a shame because the technology has such promise. The Colorado test demonstrated that the modified mosquitoes work in a controlled environment, although a few indoor cages are not the wilds of Central America, Brazil or Malaysia. To fight the sickness and death that ride inside the mosquito, the scientists' creations must conquer the jungle.

FORCED STERILIZATION

IN 2001 James was already a pioneer of modern molecular mosquito genetics—the first researcher to genetically alter a mosquito and the first to clone a mosquito gene. That year he decided to apply his knowledge to the problems of disease transmission. He wondered if he could use a strategy designed to control agricultural pests on mosquitoes instead.

A year before, Alphey, then at the University of Oxford, had developed a technique for generating fruit flies harboring genes that selectively killed females. The population-control strategy is just a postgenomic riff on sterile insect technology (SIT), which has successfully controlled crop pests for 60 years. Technicians rear vast numbers of insects, sterilizing the males with blasts of radiation. When they mate with females in local fields, the union produces no offspring. The strategy is insecticide-free, targets only the pest species and has been successfully applied many times—including a large-scale Mediterranean fruit fly (medfly) eradication program in 1977 in Tapachula.

Unfortunately, sterile insect technology has never worked with mosquitoes. Radiation severely weakens adult males, and the processes of sorting and transport kill them before they can mate. Extending Alphey's new fruit fly technique to mosquitoes, however, would enable researchers to design effectively sterile male mosquitoes from the genome up.

To kill female mosquitoes—the ones that suck blood and spread disease—James needed to hijack a genetic region that only females make use of. In 2002 James and Alphey identified a naturally occurring switch that controls flight-muscle development in females. Turn it off, and flight muscles won't develop. Female mosquitoes emerging from the pupal stage just squat on the water's surface, flightless, unable to attract mates. It was the perfect target.

Alphey founded Oxitec in 2002 to capitalize on the technology. In 2005 the Foundation for the National Institutes of Health, funded in large part by the Bill & Melinda Gates Foundation,

granted James $20 million to test genetic strategies against dengue. James gave Oxitec $5 million to build the mosquitoes.

The collaborators designed a stretch of DNA that included a handful of genes and the regulatory switches needed to turn them on and off at the correct time. The system works like a relay team. During the mosquito's metamorphosis from larva to adult, the female-specific switch flips on, activating the first gene, which produces a protein. This protein activates a second switch that kicks on gene number two, which then manufactures a toxin that destroys the female's flight muscles. The researchers also added genes for fluorescent proteins that make modified larvae glow red and green, allowing them to monitor the spread of the genes through the population.

To breed large populations of a mosquito that they had explicitly programmed to die, Alphey and James needed a way to protect the females from the toxic gene cassette until after they reproduced. The trick was lacing the water with an antidote—the antibiotic tetracycline, which blocks production of the flight muscle–destroying protein. This design is also an emergency fail-safe: if a few of these genetically modified mosquitoes escape, they cannot reproduce without the drug.

The first tests of the new breed came in 2008 and 2009, when Megan Wise de Valdez, a colleague of James's who at the time was based at Colorado State University, introduced modified males to a population of ordinary *A. aegypti* mosquitoes in the laboratory. Within five months the population crashed. The kill switch worked. The next step was to bring the modified mosquitoes into the field.

BREAKBONE FEVER

IN TAPACHULA, where James has set up his netted laboratory, dengue has long been a problem, as it has been in much of Mexico. "Dengue is my most important concern on a day-to-day basis," said Hermilo Domínguez Zárate, undersecretary of health for Chiapas, when I visited the region last year. Dengue spreads explosively, causing the most hardship in densely populated areas.

During my trip to Chiapas I toured Pobres Unidos—Poor United—an impoverished neighborhood on Tapachula's outskirts that suffered the most dengue cases in 2009 and 2010, along with Janine Ramsey, a parasitologist on James's team who leads day-to-day work at the field site, and Rogelio Danis-Lozano, a medical epidemiologist.

One home we visited belonged to Maria, who asked that I not use her last name. As with most homes in Pobres Unidos, Maria's house has only three walls, like a house on a movie set, so she has no way to keep mosquitoes out. The moist dirt floor creates a humid environment that lures the insects close. Piles of trash and dozens of containers collect rainwater, providing countless locations for mosquitoes to deposit eggs.

Danis-Lozano directed our attention to a large yellow tub brimming with freshwater and pointed to hundreds of skinny, black, threadlike mosquito larvae swimming vigorously in erratic zigzag patterns. Maria knows about dengue, of course, but Danis-Lozano discovered she had no idea that the larvae in her washtub morph into disease-spreading mosquitoes.

It is a scene that is mirrored in poor, crowded neighborhoods worldwide. More than 100 countries suffer from dengue, from Asia to Africa to the Americas. Symptoms of dengue's mild form—"breakbone fever"—mimic the flu: fever, joint and muscle pain, and crippling headaches that last about a week. A second infection can trigger potentially deadly dengue hemorrhagic fever, which induces vomiting, severe abdominal cramps, and internal hemorrhaging. Blood streams from the eyes, nose, mouth and vagina. Without treatment, hemorrhagic dengue kills up to 20 percent of its victims; with costly expert care, mortality drops to 1 percent. The annual worldwide death toll exceeds all other viral hemorrhagic fevers—including Ebola and Marburg—combined.

In 2008 epidemiologist David M. Morens and Anthony S. Fauci, director of the National Institute of Allergy and Infectious Diseases, warned that dengue is "one of the world's most aggressive reemerging infections." The frequency and magnitude of outbreaks have been rising, spread by growing international travel and the exodus of people into cities. Caseloads have doubled every decade since the 1970s. In 2009 Florida public health officials reported the first dengue cases there in more than seven decades, raising fears among epidemiologists that the disease would soon take root in the continental U.S.

One reason James decided to apply his genetic technology to the fight against dengue fever—instead of, say, malaria—is that the virus is primarily transmitted by a single species of mosquito. (Between 30 and 40 species of mosquito carry malaria.) *A. aegypti,* the world's main dengue vector, is an invasive tree-dwelling African species that hitched a ride on slave ships some 400 years ago. It is now an urbanite, breeding beside homes in anything that holds a few tablespoons of clean water. The mosquito bites during the day, so bed nets provide no protection. And it bites humans almost exclusively, drawing the nutrients that give it a life span of up to a month—plenty of time to bite and spread disease.

A. aegypti is stealthy, lacking the sharp, unnerving buzz that provokes a swift swat or panicked wave. Inside the secure insectary at the Regional Center for Public Health Research in Tapachula, I could barely hear a swarm of transgenic mosquitoes in a small cage. Laura Valerio, an entomologist at U.C. Davis, stuck in her gloved hand to point out a female. The intrusion scared the males, which took flight and zoomed around the cage. Females, however, just sat there or hopped away clumsily.

Modified mosquito larvae would later be moved to James's field site, which consists of five pairs of cages, each with a control cage housing a population of wild mosquitoes and a treatment cage where modified mosquitoes mix with locals. Each cage is guarded by multiple layers of mesh—protection against escapees—which researchers must carefully navigate through as they add new test subjects to the experiment.

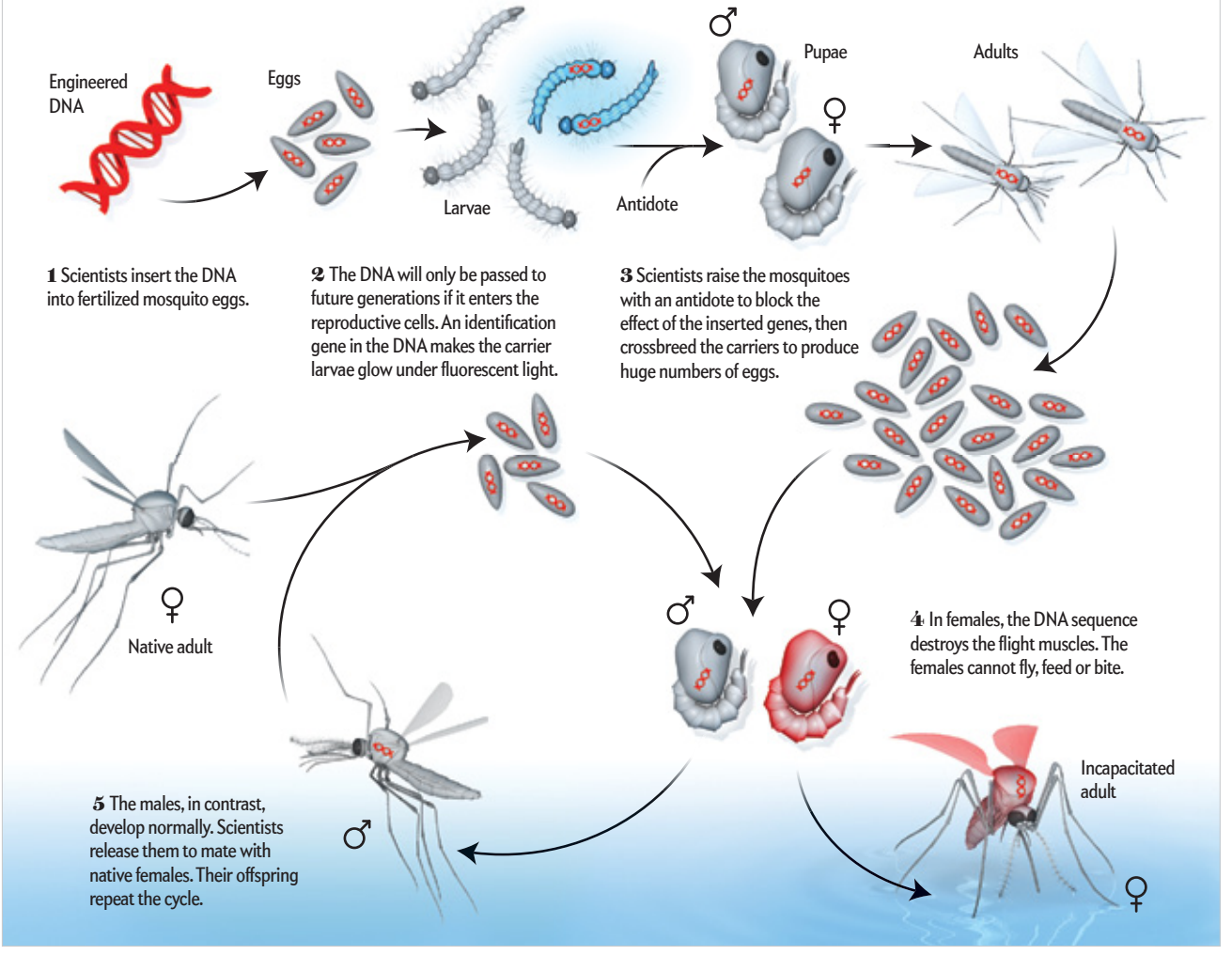
The strict protocol is an attempt to avoid past errors. Developing countries have long made a convenient location for First World field trials, but a cavalier attitude toward the local environment has led to backlash that derailed entire research programs. Perhaps no field is more fraught with abuses—both real and perceived—than genetically modified organisms.

POISON IN THE WELLS

IN 1969, FOR EXAMPLE, the World Health Organization and the Indian government teamed up to study genetic control of three mosquito species: *Culex fatigans,* which spreads filariae (parasites that cause elephantitis); *A. aegypti,* which spreads dengue and yellow fever; and malaria-spreading *Anopheles ste-*

The Female Kill Switch

The genetically modified mosquitoes in Mexico have been designed to decimate local mosquito populations. Scientists insert a genetic sequence into mosquito eggs that destroys the flight muscles of females. Male mosquitoes (which do not bite) are left to spread through the native ecosystem and pass on the crippling genes. In time, the lack of females leads to a population crash.



phensi. The U.S. government funded some of the research.

In 1972 a scientist anonymously published an article in India's *National Herald* alleging that researchers had been placing mosquitoes treated with thiotepa—described as a mustard gas derivative that causes birth defects and cancer in animals—in village drinking wells. The scientists in charge of the project issued a timid rebuttal and rebuffed subsequent interview requests from the press. Then, in 1974, the Press Trust of India ran a story with the incendiary headline "WHO Works for U.S. Secret Research in India." The article alleged that the mosquito project was being used to test the practicality of using *A. aegypti* as a biowarfare agent. India was being used to test "chemicals or methods not permitted in sponsoring countries," the account ran, also charging that *A. aegypti* was being studied because "its eggs (unlike those of other mosquitoes) can be dried, put on a piece of paper in an envelope and mailed to any part of the country where they can hatch." Although the investigators strenuously denied the allegations, the public relations debacle prompted the WHO to abandon the program.

Since then, investigators have been terrified of conducting field trials of genetically modified (GM) organisms, says Stephanie James (no relation to Anthony), director of the Grand Challenges in Global Health initiative at the Foundation for the National Institutes of Health. "There was a real psychological barrier. They knew they couldn't afford to mess up."

"All my career I've been told you'll never get people to agree to do this," Anthony James told me. At the 2005 inaugural dinner for Grand Challenges grant recipients, he consulted Jim Lavery, who specializes in the science of community engagement at Toronto's Center for Global Health Research at St. Michael's Hospital. "GM freaks people out," James said. "So how do you involve the community?"

Illustration by Emily Cooper

Lavery suggested choosing a location where dengue was a significant public health issue and control methods were failing, in a country with a stringent, sophisticated regulatory structure capable of assessing the risks and benefits of a genetically modified, dengue-fighting mosquito. That way locals would be comfortable that the effort would not endanger or exploit them. He and mosquito field-trial veteran Thomas Scott of U.C. Davis helped Anthony James assemble an international team of mosquito ecologists, anthropologists and ethicists long before he had enough mosquitoes to test.

By 2006 Tapachula was the front-runner for these trials. Mexico had national laws on genetically modified organisms and had signed the Cartagena Protocol on Biosafety—the international framework for importing them. Experience with the medfly meant the Tapachula community wasn't "freaked out" by the idea of modifying an insect, Lavery says.

"At first the request for land sounded strange," said Martimiano Barrios Matute, leader of the farming community where the experiment is based. Why would anyone want to build large cages and fill them with man-made mosquitoes? The community was also confused about what transgenic mosquitoes could do. Could escapees hurt them or their fields? Would their sterility be transferred to other insects?

James and his group addressed the community's concerns and purchased the land to build the cages through the traditional communal land-ownership program in the area. And they continue to engage the locals as the experiment continues.

In a weekly town hall gathering in the Casa de la Cultura on Tapachula's historic main square, Ramsey, the project's field site manager, described the project to an audience of community leaders, 30 men and five women. It was hard to tell she is an American expatriate as she held the room transfixed; she was animated, gesturing and joking.

When she concluded, the audience cautiously asked questions. One man asked if he could visit the mosquito cages. Another wanted to know what happens if mosquitoes escape. A young woman asked why people are against transgenics. An elderly man from a mountain village asked whether malaria and dengue are different. Ramsey answered them all, then smiled and shook hands as she left.

"Now that we understand, even more so do we like the project," said Barrios Matute, a slender soy farmer with gold-capped teeth. "It will benefit not only Rio Florido but all around Rio Florido and Mexico and other parts of the world."

THE GREAT ESCAPE

WHILE ALL THIS slow scientific and community work was going on in Mexico, Alphey was quietly taking a dramatically different approach. Last November he arrived at the annual meeting of the American Society of Tropical Medicine and Hygiene with a surprising story to tell. Beginning in September 2009, Alphey said, Oxitec had been releasing genetically modified mosquitoes on Grand Cayman island in the Caribbean. (The mosquitoes are similar to the ones being tested in Tapachula, but not identical—in the Cayman strain, both male and female mosquitoes die as larvae.) Between May and October of 2010 Oxitec released more than three million male mosquitoes, he revealed, which cut the indigenous *A. aegypti* population by 80 percent. The data have been submitted for publication.

Alphey defended his gung-ho approach, saying that Oxitec leaves outreach largely to the governments because they understand the cultural sensitivities. In Grand Cayman, outreach involved one five-minute spot on the local nightly news broadcast and a pamphlet that described the mosquitoes as sterile, avoiding any mention of genetic modification. There were no public meetings or opportunities for residents to voice concerns.

Alphey justified his actions at the Atlanta meeting. "In terms of publicity, we were only doing it in the Cayman Islands," he said. "We only need the community, people on the island, to know about it."

Mark Q. Benedict, a molecular biologist at the University of Perugia in Italy and consultant to the Gates Foundation, says Oxitec has broken no laws and calls the Cayman trials "courageous" for testing technology bound to attract "attention, both good and bad." Benedict says confused and conflicting media reports created the impression of "the lone scientist who rushes out with his bucket of mosquitoes and throws them into the environment without any oversight. That is not happening." Oxitec works with both local and national governments to gain approval before any field test.

Still, the Cayman release has provoked strong emotions—distrust, disappointment and frustration—from many of Alphey's colleagues, environmental groups and the public. "The international community was taken by surprise that this release had happened," says Bart Knols, a medical entomologist at University of Amsterdam and managing director of MalariaWorld. "Now the outside world perceives Oxitec as secretive, which makes the public wonder why. It breeds suspicion."

This is promising technology, Knols says. "If some party messes up badly and misinforms the public, the risk is that other GM trials will suffer." Now, because of Oxitec, he adds, "we have the same problems as the WHO had in India in 1976."

Other experts say the company is preying on countries with minimal bureaucracy and regulations. In the Cayman Islands, Oxitec conducted its trials in a place with a "streamlined regulatory structure," says Stephanie James, where the ink was barely dry on a biosafety bill that has yet to become law.

Malaysia was next. Amid protests from 20-plus nonprofit organizations, Oxitec launched a trial in an uninhabited area last December. A follow-up in a nearby village is pending. Even with a newly minted National Biosafety Board that monitors modified organisms and 2009 Malaysian Biosafety Act regulations, many feel that Malaysia lacks the experience to monitor the experiment, says Gurmit Singh, chair of the nonprofit Center for Environment, Technology and Development, Malaysia.

Anthony James slumped in a chair as we discussed the situation but, always diplomatic, said flatly, "That's the difficulty of working with corporations. I can't control corporate partners." He added, "If it blows up, I told you so. If not, you got lucky." James said that Oxitec's approach would be impossible in Mexico, adding that he is confident his team's community engagement activities have "set a standard for testing genetically modified organisms."

Alphey is undeterred. Earlier this year Oxitec launched a six-month trial in a poor suburb of Juazeiro, Bahia, in northern Brazil, which is plagued by mosquitoes and dengue year-round. Later this year Alphey plans to return to Grand Cayman to pit the Tapachula and Cayman strains of transgenic mosquitoes

Where Dengue Lives

Dengue fever is the most rapidly growing mosquito-borne viral disease in the world. Approximately 2.5 billion people live in countries where dengue is endemic (*below*), and the number of cases reported to the World Health Organization has been doubling each decade. Researchers have reported that releasing genetically modified mosquitoes into the wild has sharply reduced local mosquito populations.

SOURCE: *CDC HEALTH INFORMATION FOR INTERNATIONAL TRAVEL 2012*, BY THE CENTERS FOR DISEASE CONTROL AND PREVENTION, OXFORD UNIVERSITY PRESS, 2012 (*dengue risk areas*)

against the local mosquitoes to see which lives longer, flies farther and is better at mating with local females. Mosquito-control officials in Panama and the Philippines have shown interest, as have the authorities in Florida.

PERMANENT SPREAD

OF COURSE, MANY GROUPS oppose the release of any transgenic organisms, no matter how thoughtfully the scientists explain themselves beforehand. Janet Cotter, a senior scientist at Greenpeace Research Laboratories, warns that "Oxitec's release of GM mosquitoes is extremely risky. There's no such thing as 100 percent sterility, so there are going to be some fertile females that will be released, and we don't know the implications of that."

Some people wonder if it is ethical—or safe—to eliminate an organism, even in just a small geographic area. Proponents argue that *A. aegypti* is an invasive species that has evolved to exploit a solely human niche. "Urban *A. aegypti* is not part of any significant food chain," says Phil Lounibos, a mosquito ecologist at the Florida Medical Entomology Laboratory. Yet Lounibos doubts whether eliminating *A. aegypti* would stop dengue transmission permanently. "A previous campaign to eradicate this species from the Americas in the 1950s and 1960s, when it was the primary vector of urban yellow fever, failed miserably," he says. The invasive Asian tiger mosquito—another good dengue vector—readily occupies niches vacated by *A. aegypti*. Moreover, both the Cayman and Tapachula mosquito strains, even if successful, are not permanent. Migration of mosquitoes from neighboring regions into Tapachula could foil eradication attempts and mandate frequent releases of the modified males to keep the population in check.

James and his collaborators have been developing a self-sustaining but more controversial solution. It uses a "gene drive system," which promotes the spread of dengue resistance genes through a wild mosquito population, blocking the replication of at least one form of the dengue virus, known as type 2. Unlike the Tapachula mosquitoes, which die soon after release, mosquitoes outfitted with a gene drive will persist in the environment. James says field trials for gene drive systems are still a few years away.

"Something that spreads genes through populations is going to have much more difficult regulatory hurdles," James says, "so I'm happy to take something that is self-limiting, not sustainable, like [the Tapachula strain] and have that be our first shot."

Undersecretary of Health Domínguez Zárate views the genetically modified approach as "low cost and high creativity." "If dengue was something with less importance, then why modify something from nature?" he asks. "We need to respect nature as much as we can." Still, the costs of dengue outweigh the potential environmental risks, he says. "It's worth the gamble." SA

MORE TO EXPLORE

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Genetic Strategies for the Control of Dengue Transmission. http://stopdengue.hs.uci.edu

SCIENTIFIC AMERICAN ONLINE

Should scientists be releasing genetically modified insects into the wild?
ScientificAmerican.com/nov2011/dengue

Maps by George Retseck

David H. Freedman has been covering science, business and technology for 30 years. His most recent book, *Wrong*, explores the forces that lead scientists and other top experts to mislead us.

COMPUTING

A FORMULA FOR ECONOMIC CALAMITY

Despite the lessons of the 2008 collapse, Wall Street is betting our future on flimsy science

By David H. Freedman

THE MARKET CRASH OF 2008 THAT PLUNGED THE WORLD into the economic recession from which it is still reeling had many causes. One of them was mathematics. Financial investment firms had developed such complex ways of investing their clients' money that they came to rely on arcane formulas to judge the risks they were taking on. Yet as we learned so painfully three years ago, those formulas, or models, are only pale reflections of the real world, and sometimes they can be woefully misleading.

The financial world is not alone, of course, in depending on mathematical models that aren't always reliable for decision-making guidance. Scientists struggle with models in many fields—including climate science, coastal erosion and nuclear safety—in which the phenomena they describe are very complex, or information is hard to come by, or, as is the case with financial models, both. But in no area of human activity is so much faith placed in such flimsy science as finance.

It was the supposed strength of risk models that gave investment firms the confidence to leverage their bets with massive sums of borrowed money. The models would tell them how risky these bets were and what other investments would offset that risk. Yet the huge uncertainties in the models gave them false confidence. "We just don't know enough to get a good theoretical grasp of the financial risks we face," comments David Colander, an economist at Middlebury College who has studied the 2008 crisis. "The idea that we have models that can account for all the uncertainty and unpredictable behavior we see in markets is just crazy. But that's how the models have been used."

Blaming the economic calamity on risk models would be an oversimplification. Other human factors—political and regulatory ones—certainly came into play. Still, the models were arguably a crucial link, perhaps even the sine qua non of economic disaster. With so much at stake, in the past three years financial firms have spent tens of millions of dollars in buttressing their models of investment risk in the hope that new ones will preclude anything like the 2008 collapse from happening again. But that may be a vain hope or a case of wishful thinking. Experts in financial models have serious doubts about whether risk models can be im-

Illustration by Kyle Bean

proved in any fundamental way. What this means is as obvious as it is scary: banks and investment firms are leading the global economy into a future that is at great risk of repeating the past.

THE ROSY FUTURE CIRCA 2007

IN A SENSE, the downfall of the risk models in 2007 and 2008 is simple to understand. The models were supposed to simulate the complex interactions of many market forces on one another, including fluctuations in markets, changing interest rates, prices of various stocks, bonds, options and other financial instruments. Even if they did that—that's arguable—they failed to account for one important scenario: What happens when everybody wants to sell all their holdings at the same time? This is precisely what happened in those dark days of September 2008, when the U.S. government decided not to bail out Lehman Brothers, and the venerable institution defaulted on its creditors. The domino effect of collapse was averted only by massive infusions of money from the federal government.

Through 2007 the risk models indicated that the chance of any major institution defaulting was minimal. According to Marco Avellaneda, a New York University mathematician and expert on financial risk models, a big problem was that the models omitted a major variable affecting the health of a portfolio: liquidity, or the ability of a market to match buyers and sellers. A missing key variable is a big deal—an equation that predicts an airplane flight's risk of arriving late will not be very reliable if it has no mathematical term representing weather delays. And liquidity may be the most important variable in assessing the risk of default in mortgage-backed securities, the various financial instruments woven around the explosion of home lending that had taken place over the previous decade, particularly to riskier, or "subprime," borrowers. When housing prices began to fall in 2008, no one was sure just how much these instruments were worth, and as a result, trading in them ground to a halt—the instruments had become "illiquid." That left the banks that were holding them with no way of cashing out, causing panic among investors. If financial models had properly identified illiquidity risk, Avellaneda says, banks could have dropped prices of the instruments sooner, so that buyers could put less money at risk.

Omitting a key variable seems egregious, but scientists do it all the time. Sometimes they are unaware that a variable plays a key role, or they do not know how to account for it. That is a problem in climate science, Colander says, where models often have no terms to account for the effects of clouds. "Clouds control 60 percent of the weather, and models usually ignore them," he notes. "When you can't model a factor that has that kind of influence on the outcome, you have to use a lot of judgment in whether to believe the results." The problem crops up in many other situations. How do you account for the willingness of the public to get vaccines when modeling the spread of a new, dangerous form of flu? Or of the ability of emergency response teams to replace faulty parts and put out fires in overheating nuclear power plants?

Banks and investment firms are leading the global economy into a future that is at great risk of repeating the past.

Once an oversight in a model is clearly identified—typically the hard way—it may or may not be possible to remedy it. In the case of financial risk models, accounting for illiquidity isn't easy, says Robert Jarrow, a Cornell University finance and economics professor who focuses on risk models, because illiquidity tends to be much more nonlinear than the normal behavior of prices. Markets go from high liquidity to no liquidity in the blink of an eye, so it is like the difference between modeling airflow around an airplane flying at ordinary speeds and around one cracking the sound barrier (a lot of aircraft got into trouble before aerospace modelers got that one right). Jarrow is working on adding illiquidity risk to models but cautions that the resulting equations do not have single, neat solutions. Illiquidity is inherently unpredictable—no mathematical model can tell you when buyers will decide that a financial instrument isn't worth the risk at any price. To account for this behavior, models have to accommodate a range of possible solutions, and deciding between them may be problematic. "The models I'm working on are potentially useful for estimating illiquidity risk, but they're far from perfect," Jarrow says.

Unfortunately, missing illiquidity risk wasn't the only major problem. Financial risk models have been designed to focus on the risk faced by an individual institution. That always seemed to make sense because institutions are concerned only with their own risk, and regulators assumed that if the risk to each individual institution is low, then the system is safe. But the assumption turned out to be poor, says Rama Cont, director of Columbia University's Center for Financial Engineering. In a system where many interdependent components each have a low risk of failure, he notes, systemic risk can still be excessive. Imagine 30 people walking side by side across a field with their arms around one another's shoulders—any one person may be unlikely to stumble, but there's a decent chance someone in the group will, and that one stumbler could bring down a chunk of the line. That's the situation financial institutions are in, Cont says. "Up through 2008, regulators weren't considering the connections between these banks in assessing risk," he observes. "They should have at least noticed that were all highly invested in the subprime mortgage market."

THE DISASTER MAP

THE ELECTRIC POWER INDUSTRY faces an analogous problem, Cont observes. The chances of an individual power plant failing is tiny, but one does occasionally fail somewhere, and it can overload other plants on the grid, threatening a large-scale blackout of the kind the U.S. saw in 1965, 1977 and 2003. To lower such

IN BRIEF

Sophisticated models used by investment firms to calculate risk contributed to the market crash of 2008.

Despite their ubiquity, these risk models fail to take into account important forces that affect the market.

Researchers are building ways to work around these limitations and prevent a repeat market crash.

Yet these strategies may limit profits, making it unlikely that banks will adopt them without being forced to do so.

systemic risk, power companies do N-1 testing—running scenarios in which a single plant goes down in an effort to predict what will happen to the grid. But Cont points out that the power industry has the advantage of knowing how all its plants are connected. The financial system, in contrast, is a black box. "Right now nobody knows what the financial system looks like," he says. "We don't know exactly who transacts what with whom and for how much. That means we can't predict the consequences to other banks of the failure of a Lehman Brothers. In 2008 regulators had 48 hours to come up with a guess."

The obvious solution is to map out those connections. Cont has been among those actively lobbying to force financial institutions to report all their transactions to a centralized data-gathering arm set up by the government—not just domestically but also internationally because money moves fluidly across borders now. Banks are loath to report those data, however. Telling the world about an ongoing large investment could trigger copycat buying and raise prices, whereas a big sell-off could signal financial problems and lead investors to yank their money out. Those concerns can be addressed by ensuring that all reports are confidential to the data-gathering agency, Cont says. "Governments have been sharing confidential data about nuclear capabilities with international agencies for years," he explains. "Financial data aren't more sensitive than that." In fact, the Dodd-Frank Act, signed into law in the U.S. in 2010, provides for an "office of financial research" that could in principle serve as a data-collection agency for American institutions. Still, there is no evidence as of yet that any agency will be able to collect all the data needed to fashion a detailed, up-to-date map of the global financial system, which means that we may remain as oblivious to systemic risk as we were in 2007.

Even if regulators had enough data, models are not yet sophisticated enough to handle them. Existing models, argues Stanford University finance professor Darrell Duffie, are probabilistic—they make no assumptions about the future but rather kick out the chances of a default under any of the infinite number of conditions that might prevail in the future. Needless to say, doing so reliably demands not only vast rivers of data but also a superb understanding of all the various forces at play, complex math and enormous computing power. And that's just for individual banks. The notion of extending those already daunting demands to the entire financial system is almost absurd, Duffie says.

Duffie proposes an alternative: scenario stress testing, or simply spelling out a number of clear-cut future scenarios that might pose unusual risks to a bank's health. Identifying default risk under a constrained scenario is a simpler problem. For example, if you were trying to get a handle on the risk of your not being able to make your mortgage payments at some point, consider how much easier you would find it to guess how you would weather a 10 percent pay cut than to have to calculate how you would fare in the face of any or all possible future events. For banks, the selected scenarios might include a stock-market plunge, mortgage defaults, skyrocketing interest rates, and so forth. These scenarios would also include one or more financial institutions defaulting, to see how such defaults would affect the bank doing the testing. "The idea is to send huge, simulated shocks through a bank's portfolio and see how the bank would perform going forward," Duffie says. "It doesn't matter what the probability is of that particular scenario occurring; it still tells you a lot about where you might have problems."

Duffie recommends asking banks to respond to perhaps 10 or so different judiciously chosen scenarios, each involving the possible default of any of 10 different banks. Make 10 banks do that, Duffie says, and you have a 10-by-10-by-10 matrix that should give regulators a good sense of where the systemic risks lie. If key banks had been specifically asked in, say, 2006 to assess the impact on their portfolios of exploding mortgage defaults and the collapse of two giant financial institutions, regulators might well have had all they needed to know to take action in prodding the financial system to smoothly unwind its precarious position. The downside of this approach, he concedes, is that stress testing can realistically cover only an infinitesimal fraction of the scenarios that might be encountered—a bank couldn't be asked to churn out risk estimates for thousands of different scenarios involving defaults of hundreds of different banks. That means that even after scenario testing has shown the system to be relatively stable against the specified shocks, the system could still be taken down by one of the countless scenarios that weren't part of the testing.

Another problem with making complex models is that at some point their very complexity gets in the way. Paul Wilmott, an applied mathematician and former hedge fund manager, says modelers often end up bogging their creations down with dozens of terms loaded with different variables and parameters—each one adding more potential error, so that the net effect is grossly inaccurate. Wilmott advocates for finding what he calls the "math sweet spot," where a model has enough terms to provide a reasonable approximation of reality but is still simple enough for its functioning and limitations to be fully understood. Few modelers succeed in finding that balance, he adds.

It's a safe bet that financial risk models will remain unreliable for years to come. So what should we do about it? The only real option is not to trust the models, no matter how good the equations seem to be in theory. Such thinking, though, conflicts with the core ethos of Wall Street. "There has never been any incentive to distrust the models because the people in control keep making lots of money using them," Jarrow says. "Everyone thought the models were working right up until the crisis. Now they're trusting them again." The models and data are likely to improve, he asserts, but not enough to justify much faith in the results.

If regulators heeded these cautions, they would force banks to keep more cash on hand and make safer investments. The price of this reasonable caution, Avellaneda notes, will be a system that doesn't operate as efficiently—in other words, investors will get less rich off it, on average. Banks will have lower profits and less money to loan. We all will find it a little tougher to get ahead, but we will be less likely to fly headlong and clueless into a crash. That's the trade-off. SA

MORE TO EXPLORE

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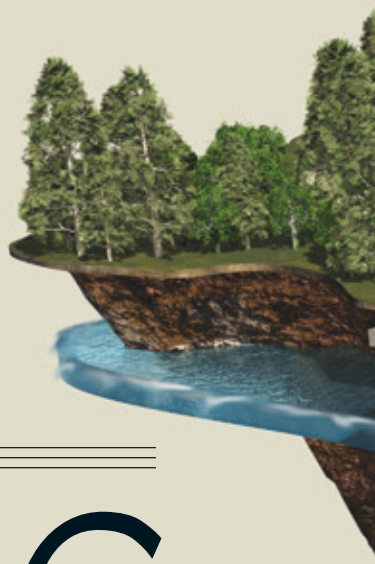
SCIENTIFIC AMERICAN ONLINE

See why models are doomed to fail at **ScientificAmerican.com/nov2011/finance**

Chris Mooney is a host of the Point of Inquiry podcast (www.pointofinquiry.org) and author of three books, including *The Republican War on Science.*



ENERGY

THE TRUTH ABOUT FRACKING

Fracturing a deep shale layer one time to release natural gas might pose little risk to drinking-water supplies, but doing so repeatedly could be problematic

By Chris Mooney

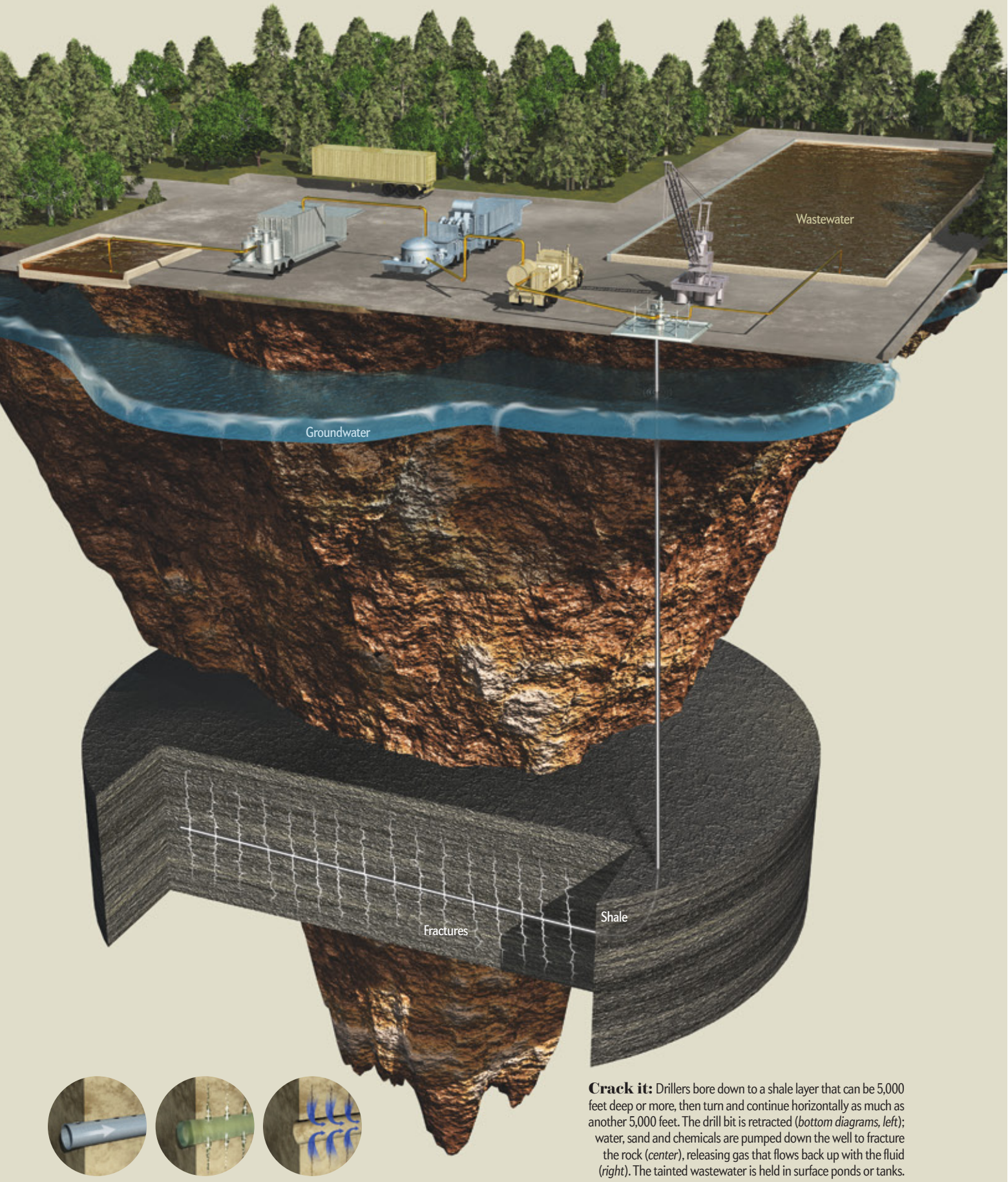
IS FRACKING POLLUTING OUR DRINKING WATER? The debate has become harsh, and scientists are speaking out.

Anthony Ingraffea, an engineering professor at Cornell University and an expert on the controversial technique to drill natural gas, has had much to say, especially since he attended a March meeting in Arlington, Va., hosted by the U.S. Environmental Protection Agency. There he met scientists from top gas and drilling companies: Devon Energy, Chesapeake, Halliburton. All had assembled to help the agency determine whether fracking, accused of infusing toxic chemicals and gas into drinking-water supplies in various states, is guilty as charged. The answer lies at the center of escalating controversy in New York State, Pennsylvania, Texas and Colorado, as well as Australia, France and Canada.

The basic technique of "hydraulic fracturing" has been used in conventional-style wells since the late 1940s. When a vertical well shaft hits a layer of shale, chemically treated water and sand are blasted down at high pressure to crack open the rock and liberate natural gas. Only recently, however, has the technique been combined with a newer technology called directional, or horizontal, drilling—the ability to turn a downward-plodding drill bit as much as 90 degrees and continue drilling within the layer, parallel to the ground surface, for thousands of additional feet. The result has been a veritable Gas Rush. Sequestered layers of methane-rich shale have suddenly become accessible. The U.S. is estimated to have 827 trillion cubic feet of this "unconventional" shale gas within reach—enough to last for de-

IN BRIEF

If fracking is defined as a single fracture of deep shale, that action might be benign. When multiple "fracks" are done in multiple, adjacent wells, however, the risk for contaminating drinking water may rise. If fracking is defined as the entire industrial operation, including drilling and the storage of wastewater, contamination has already been found. **Advanced tests,** such as putting tracer chemicals down a well to see if they reappear in drinking water, could ultimately prove whether fracking is safe or not. **Some regulators** are not waiting for better science; they are moving toward allowing fracking on an even wider scale.



Crack it: Drillers bore down to a shale layer that can be 5,000 feet deep or more, then turn and continue horizontally as much as another 5,000 feet. The drill bit is retracted (*bottom diagrams, left*); water, sand and chemicals are pumped down the well to fracture the rock (*center*), releasing gas that flows back up with the fluid (*right*). The tainted wastewater is held in surface ponds or tanks.

Illustrations by Don Foley

cades—although industry e-mails published by the *New York Times* in June suggest the resource may be more difficult and expensive to extract than companies have been claiming.

The chief hurdle is that unlike fracking of vertical wells, horizontal fracking requires enormous volumes of water and chemicals. Huge ponds or tanks are also needed to store the chemically laden "flowback water" that comes back up the hole after wells have been fractured.

As Ingraffea sat in the room, he watched industry scientists dismiss the idea that fracking has caused polluted water wells and flammable kitchen faucets. After all, the logic goes, the shale layers can be a mile or more deep, separated from shallow aquifers by thousands of feet of rock—precisely why they have been so difficult to tap until now. Fracking may be powerful, but it's not *that* powerful—not enough to blow open new fissures through that much rock, connecting horizontal well bores (called "laterals") to groundwater near the surface.

"I saw beautiful PowerPoint slides depicting what they think is actually happening," says Ingraffea, who previously worked with the global gas supply company Schlumberger but has emerged as a leading scientific critic of the gas rush. "In every one, the presenter concluded it was highly improbable." Yet, Ingraffea explains, these analyses considered only single "fracks"—one water blast, in one lateral, one time. To maximize access to the gas, however, companies may drill a dozen or more vertical wells, closely spaced, at a single site. They may frack the lateral for each well in multiple segments and perhaps multiple times.

"You've got three spatial dimensions and time" to consider, Ingraffea says. He doubts a single lateral frack can connect the shale layers to the surface. Still, he adds, "if you look at the problem as I just described it, I think the probabilities go up. How much? I don't know."

GUILT BY DEFINITION

THE SCIENTISTS and regulators now trying to answer this complex question have arrived a little late. We could have used their research *before* fracking became a big controversy. The technique is the cause of political conflict in New York, where the Department of Environmental Conservation recently unveiled a plan to give drilling companies access to 85 percent of the state's portion of the Marcellus and Utica Shale formations. Fracking would not be allowed in the New York City or Syracuse watersheds, because those water supplies are unfiltered between source and citizen.

The department based its go-ahead on reviews of various studies and says it plans to tightly regulate any drilling work. The actions essentially replace a previous statewide ban on fracking, despite the fact that the EPA is only midway through a major safety study due in preliminary form in late 2012. The department, unwilling to wait for the EPA's science, was set to issue its final regulations in October, open to public comment until early December.

The push to drill in New York before the EPA's results are ready is forcing experts to try to determine which charges against fracking hold some weight and which need new research to address. The answers to this deeply confused issue ultimately depend on competing definitions of "fracking."

If fracking is taken to refer to the entire process of unconventional gas drilling from start to finish, it is already guilty of some serious infractions. The massive industrial endeavor demands a staggering two to four million gallons of water for a single lateral, as well as 15,000 to 60,000 gallons of chemicals; multiply those quantities by the number of wells drilled at one site. Transporting the liquids involves fleets of tanker trucks and large storage containers.

Then the flowback water has to be managed; up to 75 percent of what is blasted down comes back up. It is laden not only with a cocktail of chemicals—used to help the fracking fluid flow, to protect the pipe and kill bacteria, and many other purposes—but often with radioactive materials and salts from the underground layers. This toxic water must be stored on-site and later transported to treatment plants or reused. Most companies use open-air pits dug into the ground. Many states require the bottoms of the pits to be lined with synthetic materials to prevent leakage. Some also require the pits to be a sufficient distance from surface water. The problem is that even when proper precautions are taken, pit linings can tear, and in heavy rains the pits can overflow. Under the proposed New York rules, only watertight tanks will be allowed to store flowback water, and runoff precautions must be made.

All these processes can cause accidents. "This is not a risk-free industry," explains Terry Engelder, a hydraulic fracturing expert at Pennsylvania State University who has generally been a proponent of the process but has occasionally criticized companies involved. Indeed, a series of *New York Times* exposés have documented the possible contamination of major Pennsylvania river basins such as the Susquehanna and Delaware because of inadequate handling of flowback water. In Pennsylvania, household taps have gone foul or lit on fire, and companies have been cited and fined. Most recently, the state's Department of Environmental Protection fined Chesapeake almost $1 million for contaminating 16 families' water wells with methane as a result of improper drilling practices.

These kinds of impacts can be blamed on fracking if the term refers to the whole industrial process—but not necessarily if it means just the underground water blast that fractures the rock after the drilling is done. Even the people most steeped in the issues can differ on this basic matter. "There's a real vulnerability in having chemicals at these kinds of volumes out there, but it's more an industrial kind of threat, rather than a threat from fracking itself," argues Val Washington, a former deputy commissioner of New York's Department of Environmental Conservation. But Cornell's Ingraffea sees it differently: "I just wish the industry would stop playing the game of 'fracking doesn't cause the contamination.' You've got to drill to frack. It's a matter of semantics and definition that they're hiding behind."

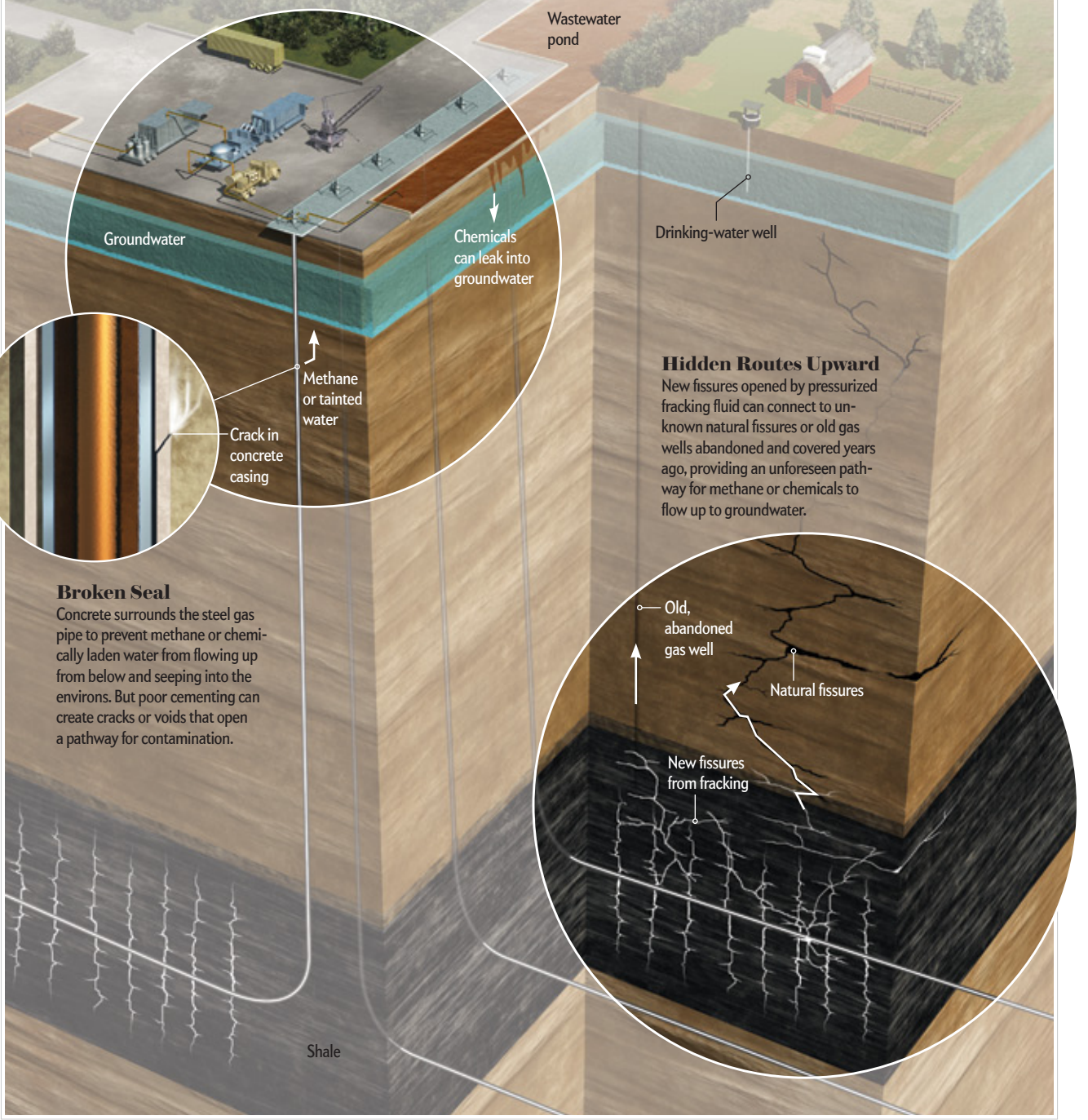
To show that fracking as *industry* defines it is the problem, you have to examine the alleged threat that is simultaneously the most publicized and yet the most uncertain—the idea that water blasts deep underground can directly contaminate drinking water, by creating unexpected pathways for gas or liquid to travel between deep shale and shallow groundwater.

CONCRETE CULPRIT

TO SEE HOW COMPLEX this issue is, consider an EPA enforcement action in 2010 against Range Resources, a Fort Worth–based gas company that plumbs sites in Texas's famed Barnett Shale. The EPA claimed that two residential drinking-water wells near

Risks to Drinking Water

Once a drill pad and wastewater pond are established, a driller may sink a dozen wells or more to fully tap the shale gas. Three spots may have the greatest potential to contaminate groundwater. Chemical-laden wastewater ponds can leak or overflow (*center*), which happened in Pennsylvania in September because of flooding by Tropical Storm Lee. Concrete that encases the vertical pipe can crack (*inset, left*), and new fissures opened by the fracking can connect to natural fissures or old wells (*inset, right*).



Broken Seal

Concrete surrounds the steel gas pipe to prevent methane or chemically laden water from flowing up from below and seeping into the environs. But poor cementing can create cracks or voids that open a pathway for contamination.

Hidden Routes Upward

New fissures opened by pressurized fracking fluid can connect to unknown natural fissures or old gas wells abandoned and covered years ago, providing an unforeseen pathway for methane or chemicals to flow up to groundwater.

two of the company's gas wells were contaminated with methane of deep, "thermogenic" origin. That kind of gas originates in shale layers, unlike "biogenic" methane, which is produced by microbes in pockets closer to the surface, where aquifers typically are. The EPA also claimed that one of the wells contained chemicals sometimes used in fracking—such as benzene—and was delivering flammable water.

The EPA ordered the company to provide clean water to the injured parties, to determine if any other nearby wells were contaminated, and to take other steps. Range Resources fought back strongly—disputing in court the claim that it bore any responsibility, noting the "long horizontal and vertical distances" involved. As of mid-September, the legal battle was in a U.S. Court of Appeals. Crucially, however, even if the EPA is correct that Range Resources is at fault, that does not mean fracking deep in the ground caused the problem. The agency asked the company to determine which "gas flow pathways" were involved—and many are possible. Gas could have migrated all the way up from the fracked shale through some unknown route. Or a faulty cement job on the vertical part of the well, much closer to the surface, could have done the trick.

Faulty cementing is the leading suspect in possible sources of contamination, and by industry's definition it is not part of fracking. On the way down, any well has to pass through the near-surface layers that contain groundwater, and it could also pass through unknown pockets of gas. Drillers fill the gap between the gas pipe and the wall of the hole with concrete so that buoyant gas cannot rise up along the outside of the pipe and possibly seep into groundwater. A casing failure might also allow the chemical flowback water, propelled by the pressure released when the shale is cracked, to leak out.

Cementing is the obvious "weak link," according to Anthony Gorody, a hydrogeologist and consultant to gas companies who has been a defender of fracking. Other scientists emphatically agree. "If you do a poor job of installing the well casing, you potentially open a pathway for the stuff to flow out," explains ecologist and water resource expert Robert B. Jackson of Duke University's Nicholas School of the Environment. Although many regulations govern well cementing and although industry has strived to improve its practices, the problem may not be fully fixable. "A significant percentage of cement jobs will fail," Ingraffea says. "It will always be that way. It just goes with the territory."

Tough sell: Strict regulations might be key to winning over citizens who fear unsafe drilling practices, such as demonstrators in Albany, N.Y., who supported a state ban.

Contamination because of bad cementing has been a long-standing problem in traditional vertical wells, which were fracked at times, too. According to former DEC deputy commissioner Washington, "we've got a lot of wells in western New York that have been producing oil and gas for decades. And fracking was the way to get the gas out of these really hard shales; that has been going on for maybe 20 years." What is different now with horizontal drilling, she says, is that "because of the depths of the gas and the combination of fracking and directional drilling, instead of 80,000 gallons of water it is now millions of gallons per fracking operation," with the big increase in chemicals that go along with it.

UNSAFE AT ANY DEPTH?

POOR CEMENTING accounts for a number of groundwater contamination cases from unconventional gas drilling—including the $1-million Chesapeake violation. "Methane migration is a problem in some areas. That's absolutely correct," Engelder says. The question is whether any *other* causes exist. If the groundwater problem really turns on cementing, you might argue that fracking as industry defines it gets a pass, and tougher regulations are needed to scrutinize companies as they drill—precisely what New York State now proposes.

The most intriguing work on possible gas migration is described in a recent paper by Jackson and his colleagues in the *Proceedings of the National Academy of Sciences USA*. It holds something for environmentalists and industrialists alike. When the hotly debated paper came out, as Jackson jokes, the responses ranged from "you saved my life" to "get a life."

Jackson's team analyzed samples from more than 60 private drinking-water wells overlying the Marcellus Shale in northeastern Pennsylvania and the Utica Shale in upstate New York. Methane existed in 51 of the wells, but wells closer to drilling sites contained considerably more of it. Chemical analyses determined that much of the methane was of the deep, thermogenic kind rather than the biogenic kind of microbes nearer the surface.

None of the samples contained fracking fluids, however, or salty brines consistent with deep shale layers. Jackson therefore thinks the likeliest cause of the contamination was faulty cementing and casing of wells. He notes another possibility: fracking may create at least some cracks that extend upward in rock beyond the horizontal shale layer itself. If so, those cracks could link up with other preexisting fissures or openings, allowing gas to travel far upward. Northeastern Pennsylvania and upstate New York are "riddled with old abandoned wells," Jackson observes. "And decades ago people didn't case wells, and they didn't plug wells when they were finished. Imagine this Swiss cheese of boreholes going down thousands of feet—we don't know where they are."

Yet if methane is getting into drinking

MIKE GROLL *AP Photo*

water because of unconventional gas drilling, why aren't the fracking chemicals? Here Jackson and Engelder can only hypothesize. When methane is first released from the rock, enough initial pressure exists to drive water and chemicals back up the hole. That flow subsides rather quickly, however. Thereafter, although gas has enough buoyancy to move vertically, the water does not.

Still, if hydraulic fractures could connect with preexisting fissures or old wells, the chemicals could pose a groundwater risk. Fracking "out of zone" can happen. Kevin Fisher, an engineer who works for Pinnacle Technologies, a Halliburton Service firm, examined thousands of fractures in horizontal wells in the Barnett and Marcellus Shale formations, using microseismic monitoring equipment to measure their extent. Fisher found that the most extreme fractures in the Marcellus Shale were nearly 2,000 feet in vertical length. That still leaves a buffer, "a very good physical separation between hydraulic fracture tops and water aquifers," according to Fisher.

Other engineers read the same kind of evidence differently. In British Columbia, Canada, regulators catalogued 19 separate incidents of "fracture communication"—new wells that ended up connecting with other wells in ways that were not expected. In one case, the communication occurred between wells that were more than 2,000 feet apart. As the British Columbia Oil and Gas Commission warned operators, "Fracture propagation via large scale hydraulic fracturing operations has proven difficult to predict." The agency added that fracture lengths might extend farther than anticipated because of weaknesses in the overlying rock layers.

None of this constitutes evidence that fracturing a horizontal shale layer has directly polluted an aquifer. EPA administrator Lisa Jackson recently stated that no such case has been documented, although she added that "there are investigations ongoing." Absence of evidence is not evidence of absence, however; each site is different. The *New York Times* and the Environmental Working Group recently revealed an alleged contamination case from 1984, which suggested that a fracked well in West Virginia may have intersected with an old, abandoned well nearby, leading to drinking-water pollution. Industry contests the validity of the case.

MORE SCIENCE, TOO LATE?

IMPLICATING OR ABSOLVING fracking, no matter how it is defined, will require more data. That's where the EPA study comes in. The agency is examining a variety of ways in which drilling could contaminate water supplies—from unlined and leaky storage pits, to faulty well cementing, to the possible communication of deep fractures with the surface. The EPA will examine five alleged cases of groundwater contamination to determine the cause, including two in Pennsylvania. The agency will also monitor future drilling activities from start to finish at two additional sites. It will also use computer modeling to simulate what is going on deep underground, where no one can watch.

Ingraffea's advice is to develop a powerful model that can iterate a scenario of multiple wells, multiple fracks, and gas and liquid movements within a cubic mile of rock—over several weeks of drilling. "You're going to need really big supercomputers," he says, to determine the possibility of contamination. "You show me that, and I'll tell you where I stand between 'snowball's chance in hell' and 'it's happening every day.' " At a minimum, Ingraffea says, such models would reveal "circumstances in which gas migration is more possible, more plausible, than other situations."

That kind of model may be difficult to find. The current standard used in academia to simulate underground reservoirs—and the one that the EPA plans to use—is called Tough 2, but Ingraffea says it is not "commercial-grade." Big corporations use their own models, and in his view "the best and the brightest in terms of people, software, instrumentation and data are all in the hands of the operators and the service companies." Ingraffea worries that Tough 2 "would have a tough time handling all the faults and joints and fracture propagation" in detail fine enough to determine whether a discrete new pathway for unwanted flow would emerge.

In the meantime, Gorody and Jackson agree that the EPA should monitor chemistry in drinking-water wells before and after drilling begins at new sites. Chemicals found only after drilling starts would significantly weaken the common industry argument that water was naturally contaminated before drilling arrived but that the residents just didn't notice.

Geoffrey Thyne, a petroleum geologist at the University of Wyoming's Enhanced Oil Recovery Institute, has another suggestion for sorting out the fracking puzzle: make companies put an easily identifiable chemical tracer into their proprietary fracking fluid mixture. If it turns up where it's not supposed to, that would be a smoking gun. Thyne says introducing a tracer would be "relatively easy," although he adds that "in general, industry does not view this suggestion favorably." The EPA says it is "considering" the use of tracers. The agency also says that much of the information it has received about the chemicals used in fracking has been claimed as "confidential business information" by the companies involved, and therefore the EPA has not made it available to the public. Legislation could change that situation.

Study by the EPA and others may bring clarity to complex, conflicting claims. But new insight may come too late. Fracking "has never been investigated thoroughly," says Amy Mall, a senior policy analyst with the Natural Resources Defense Council. "It's a big experiment without any actual solid scientific parameters guiding the experiment." Yet New York seems convinced that tight regulations will be enough to protect its citizens.

Residents opposed to fracking in New York, Pennsylvania and other states display a common lawn sign: the word "FRACK" in white letters against a black background, with a red circle and line through the word. The irony is, although it is very possible that gas companies have been guilty of carelessness in how they drill wells and dispose of waste, fracking technology itself may be exonerated. The yard signs would be wrong, yet the fears would be right. SA

MORE TO EXPLORE

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Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program. New York State Department of Environmental Conservation, September 2011. www.dec.ny.gov/energy/75370.html

SCIENTIFIC AMERICAN ONLINE

For the latest news on fracking, see ScientificAmerican.com/nov2011/fracking

DIAGNOSTICS

The Medical Sleuth

As a disease detective at the NIH, William A. Gahl unravels the cause of illnesses that have stumped other doctors

Interview by Brendan Borrell

IN BRIEF

WHO
WILLIAM A. GAHL

WHAT HE DOES
Tries to deduce the causes of diseases that elude diagnosis by other physicians

WHERE
National Institutes of Health's Undiagnosed Diseases Program

RESEARCH FOCUS
Connects genetics with pathology to understand mysterious illnesses

BIG PICTURE
Uses the most advanced medical technologies but is philosophical about the limits of what the healing arts can accomplish.

THE PATIENT HAD ENDURED 20 YEARS OF PAIN: HER CALVES HAD TURNED INTO TWO BRICKS, and she now had trouble walking. A slew of doctors had failed to treat, let alone diagnose, her unusual condition. So when her x-rays finally landed on William A. Gahl's desk at the National Institutes of Health, he knew immediately that he had to take her case.

Gahl is the scientist and physician who leads the Undiagnosed Diseases Program, which tries to unravel the underlying causes of, and find therapies for, mysterious maladies and known but rare conditions. Louise Benge's x-rays had revealed that blood vessels in her legs and feet bore a thick coat of calcium that restricted blood flow. Benge's sister, Paula Allen, along with several other members of the family, also shared the disorder. Over the course of several months Gahl identified the genetic root of the disorder—a mutation in a gene that regulates calcium—and he went on to propose a treatment with drugs already on the market. He continues to assess the treatment's value.

Gahl, 61, gravitated to disease detective work because of an early passion for the kind of puzzles found in a distinctly different discipline. He dreamed of becoming a mathematician until he took a biochemistry course as a college sophomore at the Massachusetts Institute of Technology. At the time that his interest shifted, scientists were beginning to recognize that a wide range of rare genetic diseases responsible for heartbreaking physical deformations and retardation can arise from a single, defective enzyme.

The potential to solve such challenging medical puzzles and help patients appealed to Gahl, who went on to make key discoveries in the treatment of cystinosis, Hermansky-Pudlak syndrome (albinism), and other little-known disorders before launching the NIH's

Photograph by Erika Larson

Undiagnosed Diseases Program in 2008.

Although Gahl embraces cutting-edge medical technology and has butted heads with the U.S. Food and Drug Administration to improve the availability of treatments for patients with rare diseases, he remains philosophical about constraints on medicine imposed by a world in which health costs seem to go in only one direction. In a recent interview, Gahl discussed the problems he faces as a medical detective and as an advocate for his patients and others like them. Edited excerpts follow.

SCIENTIFIC AMERICAN: How do you decide which cases to accept?

GAHL: We want to make diagnoses, but we also want to advance medicine and science. We consider whether a patient might have a new disease and whether we have a chance to find the genetic and the biochemical basis of it. There really is a huge amount of judgment involved, and we rely on our consultants, many of whom are experts in the particular symptomatology, to give me an opinion, and then I make a final decision on which cases to accept.

I would say, 90 percent of the time, it's straightforward whether we accept a case or not. A few cases are really tough judgment calls. Of the 1,700 files we have received, we have accepted about 400.

How do people find you in the first place?

They generally hear about us from the press and from advocacy groups. Some of our colleagues have heard about the program, and of course those are the best cases. Anyone is free to apply as long as they provide their medical records and a letter from their doctor.

What was the first step after you accepted Louise Benge and her sister as patients?

At this point, we had already seen their x-rays and other medical records, and they needed to come to Bethesda for about a week so we could conduct our own tests and obtain biological samples. Because both parents were healthy, we knew that the disease was caused by a recessive mutation. Each parent must have had only one copy of the genetic mutation, whereas the affected children would have two copies. We first identified the general region where the mutation was located in the genome and then used targeted sequencing to find an error in a specific gene, called *NT5E,* involved in producing the nucleoside adenosine [involved in a wide range of biochemical processes]. We also found two separate families with a similar condition and identified their mutations.

Rare diseases as individual diseases are really uncommon, but as a group, they are not. Everyone in the country knows a family member or friend who has one.

Once you've identified the mutation, are you done?

No, the next step is to connect the genetics with the pathology. Cynthia St. Hilaire in the lab of Manfred Boehm, an expert in cellular and molecular biology of the cardiovascular system, cultured the patients' skin cells for a series of in vitro experiments. By inserting a normal copy of the *NT5E* gene into the cells, they showed that the cells could function normally. Then they did a second experiment, adding adenosine to the cells, and found that calcification was also reduced. These experiments gave us a better understanding of the role that adenosine plays in regulating calcium. For various reasons, we can't just give patients adenosine, but we think we can treat this condition with a class of osteoporosis drugs known as bisphosphonates. We're still waiting to see whether these drugs work.

You have two professions, as both doctor and scientist. What is the difference between seeing a patient and doing science?

One has to be dispassionate in both worlds and also passionate in both worlds. Seeing a patient is more complicated than doing science because the human being has so many aspects. There's the family, the relationship with you, the trust or lack of trust, and the hope, and a huge amount of follow-up and responsibility are needed. We can drop experiments, but we can't drop patients.

You can become emotionally attached to patients, but you shouldn't become too attached, because many of those patients are going to die. It really is a balance that needs to be established for a patient-doctor relationship, and that's very different from the relationship you establish with your laboratory when you do experiments. Yet you need an element of passion in your experiment, too, because otherwise you'll give up too soon.

How do you maintain your compassion in the face of so many tough cases?

Well, it is a problem, and it's a problem for physicians in general because physicians aren't used to failure. I have come to accept failure as inevitable in some cases. We need the successes—however few they are—to buoy us against the onslaught of failures that we have. I try not to think of our failures and just think of the cases that we've actually solved or the people that we've helped.

Over the past two years we've heard a lot about the rising cost of medical care. What obligation does a society with limited resources have to treat patients with rare diseases?

Rare diseases as individual diseases are really uncommon, but as a group they are not. I would venture to say that practically everybody in the country either has someone in the extended family or a friend who has a rare disease.

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I believe a society is measured and judged by how it treats its least fortunate. Patients with rare diseases are abandoned people. They're abandoned by the medical profession, and they're often isolated by their relatives and friends because they can't put a name to their disease. Many of them will go into their doctors' offices and even their doctors will not want to see them, because without a diagnosis the physician feels very uncomfortable and inadequate.

There are cases where we will confirm a patient's worst fears of a poor prognosis, and they will thank us for it and hug us because now they have some idea of what's going on in the future. The uncertainty is gone. They can put a label on it, and this means an awful lot to people. More than I would ever guess.

It's also important to recognize that there are examples where the findings in a rare disease have applicability to common diseases. By studying Louise Benge's condition, for instance, we have identified a new pathway that alters calcification in blood vessels and bones. This discovery may have implications for heart disease, where calcium builds up on the coronary arteries, restricting blood flow.

Have you ever tried to estimate what the cost is of a single diagnosis through the program?

In the first two years, my service saw 160 patients and provided about 50 diagnoses, including about 15 that were of really rare known diseases. The cost was about $5 million, so that is about $100,000 apiece. Keep in mind, some of these patients have already had million-dollar workups. They've gone to the Mayo Clinic, Cleveland Clinic, Johns Hopkins, Harvard, Stanford, before coming to us.

On the other hand, our work provides ancillary benefits. We've discovered one new disease, and the program has provided the groundwork for finding many new diseases. We expanded our knowledge of several disorders, such as congenital disorder of glycosylation type 2B and identified a mutation involved in a neurological disease that involves spinocerebellar ataxia and spastic paraplegia.

For those we didn't diagnose, we provided hope and symptomatic therapy, so I think the money was well spent.

But there must be a financial limit that your group sets?

We don't have a lot of restrictions on how we spend our money, but we have only a total amount in the kitty. So we have to make triage decisions the same way that people make life and death decisions on a battlefield. Those triage decisions will have to do with monetary resources and physician time resources.

When we gauge the value of a diagnosis, we have to do it against the value of the next patient's diagnosis or that of 10 other people. Basically all patients want us to pursue their diagnosis to the ends of the earth. Important determinations must be made. We will not be performing whole-genome sequencing, but we will sequence just the coding portions of the genome, known as the exome. On the other hand, we can also gain a great deal scientifically if we spend more to sequence an entire family. We make judgments that incorporate both the probability of success and the financial cost.

If doctors wanted to start ordering exome sequences for diagnosis in their practices, would that raise legal issues?

Currently whole-exome sequencing is not approved for clinical laboratory testing. We use it to find the gene that is causing the disease, at a cost of about $4,000; that price is going down rapidly. Once we're pretty darn sure of the gene, we order the certified test and pay for it. Then we can tell the patient the diagnosis. Right now if doctors in the field have a patient with a degenerative disease such as spinocerebellar ataxia, which can have many different known genetic causes, they have to order tests through commercial molecular diagnostic firms that have patented each of those gene tests separately. That can cost tens of thousands of dollars.

What's going to happen, I think, is that sequencing companies will routinely begin to interpret their tests for physicians, in which case legal issues may start to come into play.

Do you worry about other issues that may arise when whole-genome sequencing becomes more widespread?

What if there's a risk factor for disability and that risk factor becomes part of the patient's record and somehow the insurance companies get access to it? Those are the things that might come out from whole-genome sequencing, and I think our society has to deal with how we're going to protect patients from discrimination that might emanate from that. When people submit themselves to whole-genome or whole-exome sequencing, they should be given the opportunity to decide how those data are handled.

You have often been compared to Dr. Gregory House, the fictional television medical sleuth and Vicodin addict. Have you been contacted by the show in any way?

I don't think they want to contact me. I was interviewed for CNN, and they asked how I would compare myself to Dr. House. I said, "Well, I wouldn't, because I'm not a sociopath, for one thing, and I'm not on drugs." But the big difference is that our patients have chronic diseases that won't be solved in 60 minutes. They're true human-interest stories. They aren't made up. These patients are enough to make you cry. SA

Brendan Borrell *is based in New York City and frequently writes about science and the environment for* Scientific American *and* Nature.

MORE TO EXPLORE

NT5E Mutations and Arterial Calcifications. Cynthia St. Hilaire et al. in *New England Journal of Medicine,* Vol. 364, No. 5, pages 432–442; February 3, 2011.

The NIH Undiagnosed Diseases Program. William A. Gahl and Cynthia J. Tifft in *Journal of American Medical Association,* Vol. 305, No. 18, pages 1904–1905; May 11, 2011.

Medical Mysteries and Rare Diseases. William A. Gahl gives a talk at TEDxCMU. http://bit.ly/oUsSD4

SCIENTIFIC AMERICAN ONLINE

See a video of Louise Benge and Paula Allen at ScientificAmerican.com/nov2011/diagnostics

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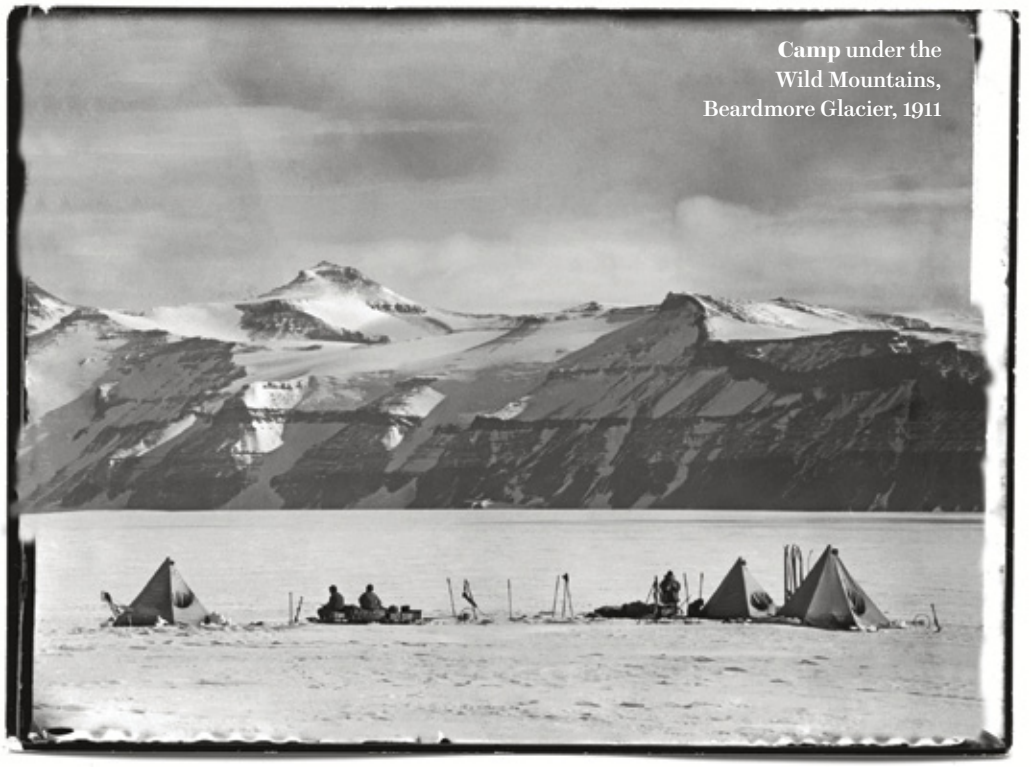
The Lost Photographs of Captain Scott: Unseen Images from the Legendary Antarctic Expedition

by David M. Wilson. Little, Brown, 2011 ($35)

One hundred years after Captain Robert Scott's trip to the South Pole, his own photos of the otherworldly polar landscape and his crew have been collected for the first time. Historian David M. Wilson, great-nephew of an expedition member, provides context for the haunting images.



Camp under the Wild Mountains, Beardmore Glacier, 1911

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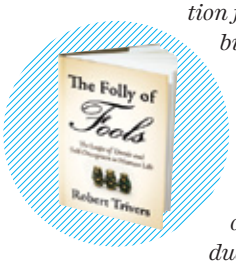
EXCERPT

The Folly of Fools: The Logic of Deceit and Self-Deception in Human Life

by Robert Trivers. Basic Books, 2011 ($28)



"It's not a lie if you believe it." *So remarked George to Jerry in a classic* Seinfeld *line that turns out to encapsulate a scientific explanation for why we lie. Evolutionary biologist Robert Trivers of Rutgers University asks why humans continually deceive themselves and concludes that we do this so we can fool others and thereby enhance our own survival and reproduction. Here he describes deception in children.*

"Children show a wide array of deception by ages two and three, and the earliest clear signs appear at about six months. Fake crying and pretend laughing are among the earliest. Fake crying can be discerned because infants often stop to see whether anyone is listening before resuming. This shows that they are capable of moderating the deception according to the victim's behavior. By eight months, infants are capable of concealing forbidden activities and distracting parental attention. By age two, a child can bluff a threat of punishment, for example, by saying, 'I don't care,' about a proposed punishment when he or she clearly cares. In one study, two-thirds of children age two and a half practiced deception at least once in a two-hour period.... Lies to protect the feelings of others—so-called white lies—appear only by age five....

"As children mature, they become increasingly intelligent and increasingly deceptive. This is not an accident. The very maturing capacity that gives them greater general intelligence also gives them greater ability to suppress behavior and create novel behavior. There is also clear evidence that natural variation in intelligence, corrected for age, is positively correlated with deception. A child is left in a room and told not to look in a box. By the time the experimenter returns, most children have peeked. Now they are asked whether they peeked. Most say no, and the brighter the children are on simple cognitive tests, the more likely they are to lie. Even health of the child at birth ... is positively correlated with lying. Because we experience deception aimed toward ourselves as negative does not imply that as deceivers we experience it as negative, at least when undetected."

ALSO NOTABLE

Fool Me Twice: Fighting the Assault on Science in America, by Shawn Lawrence Otto. Rodale, 2011 ($24.99)

Who's in Charge? Free Will and the Science of the Brain, by Michael S. Gazzaniga. Ecco, 2011 ($27.99)

Explorers of the Nile: The Triumph and Tragedy of a Great Victorian Adventure, by Tim Jeal. Yale University Press, 2011 ($32.50)

A Great Aridness: Climate Change and the Future of the American Southwest, by William deBuys. Oxford University Press, 2011 ($27.95)

Thinking, Fast and Slow, by Daniel Kahneman. Farrar, Straus and Giroux, 2011 ($30)

Secret Weapons: Technology, Science and the Race to Win WWII, by Brian J. Ford. Osprey, 2011 ($25.95)

Reactions: The Private Life of Atoms, by Peter Atkins. Oxford University Press, 2011 ($24.95)

Sybil Exposed: The Extraordinary Story behind the Famous Multiple Personality Case, by Debbie Nathan. Free Press, 2011 ($26)

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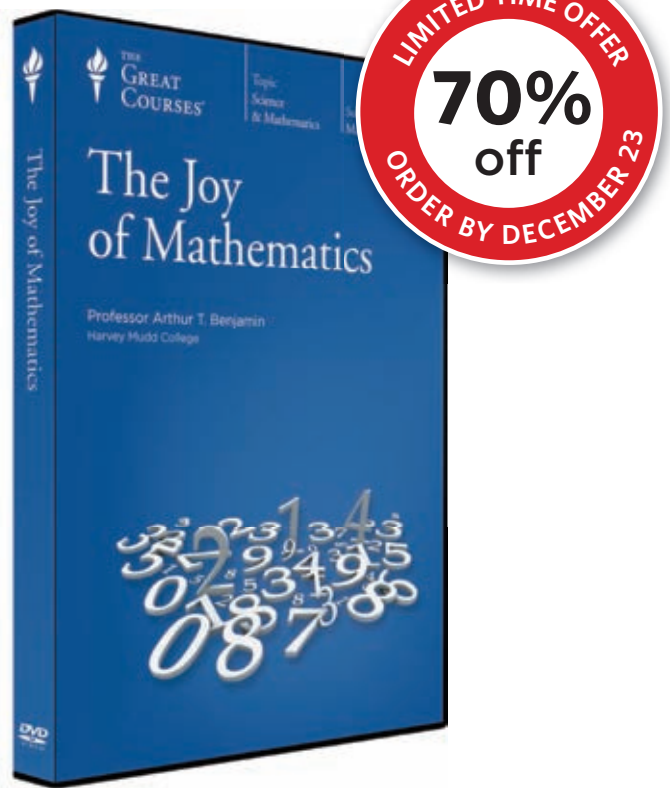

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Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His new book is *The Believing Brain*. Follow him on Twitter @michaelshermer

The Real Science behind Scientology

It's not what you think

In the 1990s I had the opportunity to dine with the late musician Isaac Hayes, whose career fortunes had just made a stunning turnabout upward, which he attributed to Scientology. It was a glowing testimonial by a sincere follower of the Church, but is it evidence that Scientology works? Two recently published books argue that there is no science in Scientology, only quasireligious doctrines wrapped in New Age flapdoodle masquerading as science. *The Church of Scientology,* by Hugh B. Urban, professor of religious studies at Ohio State University, is the most scholarly treatment of the organization to date, and investigative journalist Janet Reitman's *Inside Scientology* is an electrifying read that includes eye-popping and well-documented tales of billion-year contracts, aggressive recruitment programs and abuse of staffers.

The problem with testimonials is that they do not constitute evidence in science. As social psychologist Carol Tavris told me, "*Every* therapy produces enthusiastic testimonials because of the justification-of-effort effect. Anyone who invests time and money and effort in a therapy will say it helped. Scientology might have helped Isaac Hayes, just as psychoanalysis and bungee jumping might have helped others, but that doesn't mean the intervention was the reason. To know if there is anything special about Scientology, you need to do controlled studies—randomly assigning people to Scientology or a control group (or a different therapy) for the same problem." To my knowledge, no such study has been conducted. The real science behind Scientology seems to be an understanding of the very human need, as social animals, to be part of a supportive group—and the willingness of people to pay handsomely for it.

If Scientology is not a science, is it even a religion? Well, it does have its own creation myth. Around 75 million years ago Xenu, the ruler of a Galactic Confederation of 76 planets, transported billions of his charges in spaceships similar to DC-8 jets to a planet called Teegeeack (Earth). There they were placed near volcanoes and killed by exploding hydrogen bombs, after which their "thetans" (souls) remained to inhabit the bodies of future earthlings, causing humans today great spiritual harm and unhappiness that can be remedied through special techniques involving an Electropsychometer (E-meter) in a process called auditing.

Thanks to the Internet, this story—previously revealed only to those who paid many thousands of dollars in courses to reach Operating Thetan Level III (OT III) of Scientology—is now so widely known that it was even featured in a 2005 episode of the animated TV series *South Park*. In fact, according to numerous Web postings by ex-Scientologists, documents from court cases involving followers who reached OT III and abundant books and articles by ex-members who heard the story firsthand and corroborate the details, this is Scientology's Genesis. So did its founder, writer L. Ron Hubbard, just make it all up—as legend has it—to create a religion that was more lucrative than producing science fiction?

Instead of printing the legend as fact, I recently interviewed the acclaimed science-fiction author Harlan Ellison, who told me he was at the birth of Scientology. At a meeting in New York City of a sci-fi writers' group called the Hydra Club, Hubbard was complaining to L. Sprague de Camp and the others about writing for a penny a word. "Lester del Rey then said half-jokingly, 'What you really ought to do is create a religion because it will be tax-free,' and at that point everyone in the room started chiming in with ideas for this new religion. So the idea was a Gestalt that Ron caught on to and assimilated the details. He then wrote it up as 'Dianetics: A New Science of the Mind' and sold it to John W. Campbell, Jr., who published it in *Astounding Science Fiction* in 1950."

To be fair, Scientology's Xenu story is no more scientifically untenable than other faiths' origin myths. If there is no testable means of determining which creation cosmogony is correct, perhaps they are all astounding science fictions. SA

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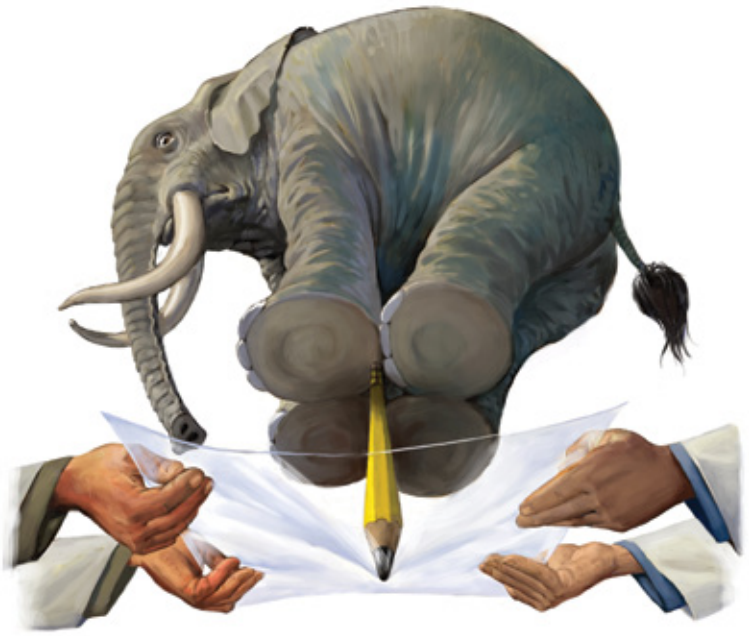
The ongoing search for fundamental farces

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.



Balancing Act

A statement about a material raises heavy issues

The tweet, posted on September 1, 2011, by @qikipedia, read in its entirety: "It would take an elephant, balanced on a pencil to break through a sheet of graphene the thickness of cling film." Some detective work revealed that the statement originated with mechanical engineering professor James Hone of Columbia University, who said in 2008, "Our research establishes graphene as the strongest material ever measured, some 200 times stronger than structural steel. It would take an elephant, balanced on a pencil, to break through a sheet of graphene the thickness of Saran Wrap."

The professor's contention raises numerous questions, the first one being "What is graphene?" Microsoft Word doesn't know—it keeps giving graphene the red squiggly underline, which means, "Surely you mean grapheme." (I surely don't, despite the fact that I'm littering this page with graphemes.)

Fortunately, the Wikipedia entry on graphene includes this definition from a paper by Andre Geim and Konstantin Novoselov, who won the 2010 Nobel Prize in Physics for their work on the miracle substance: "Graphene is a [sic] flat monolayer of carbon atoms tightly packed into a two-dimensional (2D) honeycomb lattice, and is a basic building block for graphitic materials of all other dimensionalities. It can be wrapped up into 0D fullerenes, rolled into 1D nanotubes or stacked into 3D graphite." Picture chicken wire, but with each connection point being a carbon atom. The result of that mental metamorphosis is graphene. (Well, virtual graphene.)

Professor Hone has better things to do—such as figuring out how to layer enough sheets of graphene together to get it to be the thickness of Saran Wrap—than to deal with the rest of my questions. So I leave them to you, gentle reader. And away we go.

Is the pencil vertical or horizontal? Let's assume vertical, so that the entire weight of the elephant is concentrated at a single point on the graphene. Other than for writing on a wall, a horizontal pencil is useless in most cases, including pencil cases.

What is the pencil made of? You can't expect a regular old pencil to carry the weight of an elephant. The obvious answer is graphene, rolled into a massive nanotube. (Massive for a nanotube, regular size for a pencil.) The manufacturer could include a thin cylinder of graphite within the roll of graphene so that the pencil could actually be used to write, but that strikes me as pedantic. (Then again, if it can't write, is it really a pencil? Perhaps not. I've been told that I can't write, and I'm certainly not a pencil.)

Anyway, we have the graphene Saran Wrap and the graphene pencil. The next question is, How do you get the elephant onto the pencil? Wait a second, back up. Is it an African elephant, weighing in at, say, 15,000 pounds, or is it the more diminutive Asian elephant, tipping the scales at a more manageable 10,000 pounds?

The two creatures also have vastly different temperaments. You might get away with this stunt using an Asian elephant, but I'd stay away from trying to get an African elephant onto a pencil, especially a bull African elephant. He might not be able to break the graphene pencil, but he'll almost certainly destroy the lab in his zeal to avoid being balanced on it.

Come to think of it, there's a lot we don't know about the elephant. Is it a full-grown elephant or a baby elephant? A baby Asian elephant is going to be the easiest choice to get onto the pencil. As it approaches the graphene, do the researchers play Henry Mancini's "Baby Elephant Walk"? If not, why not? These opportunities don't come along every day.

Will the weight of the baby elephant concentrated at the tip of the pencil be enough to pierce the graphene? If it was going to require the weight of an adult African elephant balanced on the pencil, I doubt the baby elephant, at about 230 pounds, has enough heft. So if you put the full weight of our adorable little elephant onto the superstrong nanotube pencil, I have to figure that, although the Saran Wrap might hold, the elephant won't. The pencil will puncture the poor baby's hide and get swallowed up. Now you have a wounded baby Asian elephant bleeding all over your graphene, a mother elephant going out of her mind and a protest by People for the Ethical Treatment of Animals.

Ultimately we'll have to go with a full-grown Asian elephant, itself necessarily encased in a protective layer of graphene, situated above the graphene sheet, balanced on a graphene pencil. And unlike this entire column, it can't be missing the point. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/nov2011

Illustration by Matt Collins

Do you long for a new world? A world of no conflict, no jealousy, no unkind words. A world in which people think, say, and do what is rational and honest, resulting in behavior that is caring, trustworthy, and productive.

Enlarge the picture of that ***new world*** whose people hold no grudges nor compete to exert control. Their behavior conforms to a ***natural law,*** causing them to overcome the stress and pressures of their former lives.

Picture other details of a ***new-world*** society. People's activities need no supervision as they are guided by what reality calls for. There are no locks on doors or windows, no legal documents to assure honest compliance, no addictions, no crime, no poverty, and no deprivation of any rightful thing or opportunity.

There are no scoldings or punishments and no stress. There is liberation of men, women, and children of every race from the tyranny of prejudice. There is plentiful food and shelter. There is nonpolluting transportation. In this ***new world*** there is full employment with unique opportunities available to everybody.

More important, there is fellowship among people. There are neither strangers nor anyone to fear. There is stimulating activity as people reason from reality to learn from it and to be guided by it.

Daily life is an exciting adventure. Since there are no conflicting thoughts, there are no confrontations.

As people consult nature's storehouse of knowledge, there are spectacular accomplishments. No prizes are awarded, as everybody is attending the ***university of life*** and learning from its boundless source.

Reality results from whatever the natural laws deliver.

What creates a new world? The answer is found by people that conform to a natural law created by whoever or whatever created natural laws. This law identified by Richard W. Wetherill in 1929 is called the ***law of absolute right: Right action gets right results***.

The law defines right action as thoughts, words, and deeds that are rational and honest—nonconformance prolongs society's ***old-world*** problems, failures, and afflictions.

At present writing, billions of people worldwide, trying to satisfy their conflicting motives, are unknowingly causing the societal chaos that is blocking the birth of a ***new world***.

Conforming to the principles of the ***law of right action*** begets a new world for those willing to participate. Unlike mankind's laws, philosophies, and beliefs, the behavioral law is not a product of human intelligence. The ***new world*** comes into being worldwide for people who reason from nature's ***law of absolute right***.

Scientific research and discovery require identifying various aspects of nature to learn their principles and functions. In the process researchers have mapped the body's DNA, planet Earth, large areas of space, tectonic plates, and the ocean floor, showing that to acquire knowledge and dispel beliefs, researchers study nature.

By turning to the creator, Wetherill had insight into a behavioral law, establishing a new world. Whoever or whatever created the universe, its people, and its laws intended a peaceful and productive society.

Becoming rational and honest enables people to function in a world envisioned for the human race by whoever or whatever created that precious law!

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Natural-law Essays and Books describe the function of nature's law of absolute right. Read, download, print books and essays FREE.

If you lack access to the Website, our books are also available in print at low cost. For an order form, write to The Alpha Publishing House, PO Box 255, Royersford, PA 19468.

This public-service message is from a self-financed, nonprofit group of former students of Mr. Wetherill.

November 1961

Teaching Machines

"Like all useful machines, the teaching machines developed slowly from the need to do a job more effectively than it could be done otherwise. They have evoked all the reactions, including the hostile ones, that we have learned to expect from a new kind of machine. Some people see the machines as a threat to the teacher, which they are not. Some fancy that they will make education a cold, mechanical process. Others fear that they will turn students into regimented and mindless robots. Such fears are groundless. The purpose of a teaching machine can be simply stated: to teach rapidly, thoroughly and expeditiously a large part of what we now teach slowly, incompletely and with wasted effort on the part of both student and teacher. —B. F. Skinner"

November 1911

Got a Match?

"It has been estimated that, for each minute of time, the civilized nations of the world strike three million matches. The importance of the industry which turns out the little splinters of wood tipped with sulphur is only recognized when the average smoker tries to contemplate his predicament if he had to go back to the time when he had to coax a spark from a tinder-box."

Edison on City Lights

"I noted that the lighting of the leading European cities does not compare with that of New York. Berlin and Paris are about equally well lighted; but Berlin is continually putting in more light, and before long she will greatly surpass Paris in this regard. Night life in Berlin is increasing very rapidly. It was observable that throughout Europe the night life is on the increase in those cities which have cheap water power, and there seems to be a correlation between the night life and the industrial activity of the people. In towns where the people have cheap and plentiful light, they keep later hours, and this seems to have the effect of mitigating the phlegmatic character of their temperament. —Thomas A. Edison"

Marie Sklodowska Curie

"Only a few days ago we heard the news that Mme. Curie has been honored with the Nobel prize a second time, on this occasion in the division of chemistry. The list of medals and prizes which have been awarded to Mme. Curie in foreign countries is too long to quote. In addition to the numerous researches in radio-activity which she made in collaboration with her husband, Mme. Curie has published a great may independent papers, and a volume, 'Investigations of Radio-Active Substances,' in which the results of their co-operative researches, including the epoch-making discovery of radium, are set forth."

The complete article on Curie is at www.ScientificAmerican.com/nov2011/curie

November 1861

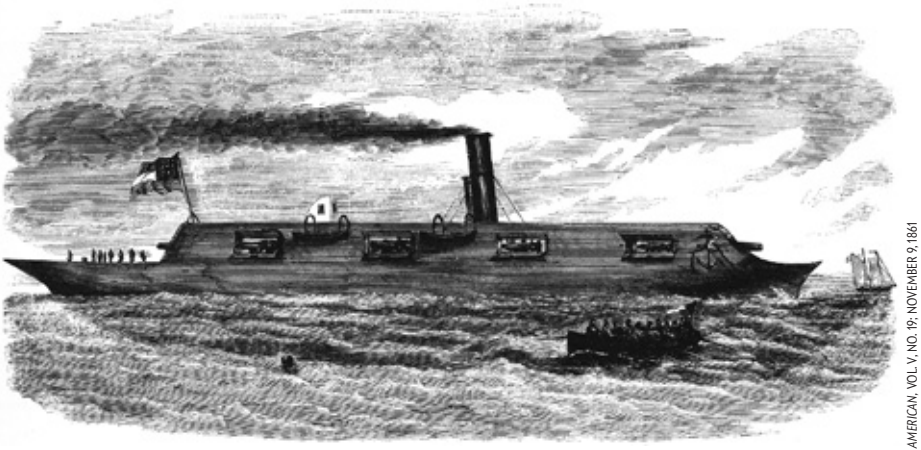
The Mighty *Merrimac*

"The accompanying engraving of the *Merrimac* is from a sketch furnished by a mechanic who came from Norfolk under a flag of truce. He says that he worked on her and is of course familiar with her appearance. The *Merrimac* was partially burned and then sunk at the time of the destruction of the Gosport Navy Yard last spring. We have had accounts from time to time that the secessionists had succeeded in raising the *Merrimac* and were repairing her. The mechanic who furnishes the sketch says that her hull has been cut down to within three feet of her light-water mark, and a bomb-proof house built on her gun deck. Her bow and stern have been steel clad with a projecting angle of iron for the purpose of piercing a vessel."

Four months later this warship, renamed the CSS Virginia, *battled the Union ship* Monitor *in the world's first duel between armor-clad vessels.*

Ghost Photo

"The *London Review,* in an article on the tendency in modern literature to the revival of ghost stories, suggests to the writers that as a verification they obtain photographs of their spectral visitors. It says: 'Now, if the specter can ask the favor let science do it a good turn. Let optics and chemistry catch this modern ghost and photograph it! It can fix the tails of comets and the atmosphere of the sun; a ghost can hardly be less material. The photographer's plate is liable to no delusions, has no brains to be diseased, and is exact in its testimony.'"



An early ironclad warship makes an appearance (in a slightly fanciful etching): CSS *Virginia*, also called the *Merrimac*, 1861

SCIENTIFIC AMERICAN, VOL. V, NO. 19, NOVEMBER 9, 1861

SCIENTIFIC AMERICAN Travel

BRIGHT HORIZONS 12

APRIL 12-20, 2012 ✸ RHINE RIVER CRUISE ✸ www.InsightCruises.com/sciam12

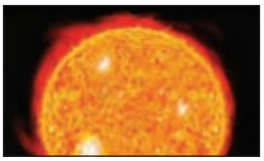
Curious how magic works? Ready to absorb the latest science, without distraction? Join Scientific American for current science and immersion into German culture and scenic beauty, on a river cruise sailing from Amsterdam, The Netherlands to Basel, Switzerland on AMA Waterways's AmaCello, April 12–20, 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.

Game for fine times on the Rhine? Visit InSightCruises.com/SciAm-12 or call our Concierge at 650-787-5665 for the full scoop. Make your reservation now, as capacity is limited.

The cruise fare is approximately $3,674 for either a Category A or B cabin, per person. The Bright Horizons Program costs $1,195. Taxes and fees are $199 per person. Gratuities are €105. Program subject to change. **For more info please call 650-787-5665 or email us at Concierge@InSightCruises.com**



SOLAR SCIENCE

Speaker: Pål Brekke Ph.D.

A Cosmic Voyage Through the Universe

Since the ancients' observations and Galileo's discoveries, humans have been driven to explore the universe. Deep-space finds by sophisticated telescopes and satellites stoke our curiosity. Using imagery from modern space-based telescopes, take a cosmic journey. We'll boldly go where new solar systems are born and visualize black holes, neutron stars, and supernovas.

The Stormy Sun — How Does it Affect our Technology Based Society?

100 years ago, solar storms occurred without humans noticing the damage they caused. Today with satellite systems, GPS, and electrical grids vulnerable to solar weather, it's a different story. Learn about the impact of solar weather activity as well as forecasting, early-warning, and prediction resources. Find out what's hot in sun science!

The Northern Lights: A Message from the Sun

What is more beautiful than the aurora borealis dancing across the sky? Spanning the myths and modern science behind the northern lights, we'll discuss coronal mass ejections, the magnetosphere and solar wind, and the Earth's magnetic field and solar particles. Learn where to see this phenomenon that has fascinated through the ages, and how to predict its appearances.

Does the Sun Contribute to Climate Change?

In the last 150 years the Earth has warmed ~0.7°C. In the same period both concentrations of atmospheric greenhouse gases and the level of solar activity increased. Related phenomena? It's not a trivial task to untangle the two. Dr. Pål Brekke summarizes current understandings and discusses his opinion that the future holds surprising answers on why solar activity varies and the relationship of solar activity and Earth's climate.

ALPINE ARCHAEOLOGY

Speaker: Patrick Hunt, Ph.D.

Medicine in the Ancient Western World

What is the the most profound secret about medicine in the ancient world? Arguably, that while deep superstition and ignorance were elements of medicine in antiquity, logic and rationality entered medical practice early on. Egypt, Mesopotamia, Greece, and Rome have long medical traditions. Hear how significant aspects of ancient medicine are surprisingly familiar.

Science in Archaeology: New Perspectives on Old Problems

Ötzi the Iceman was discovered as a frozen 5300 year-old "ice mummy," high in the Alps in 1991. Through Ötzi's case learn how forensic investigations in microbiology, chemistry, physics, and geology help bring ancient wonders to life.

Four Horsemen of the Apocalypse: Climatic Problems, Famine, Disease, War, and Mass Death in History

Human history records apocalyptic cycles of connected catastrophes through environmental or human causation. Through such disasters, humans have always been susceptible to food-supply famine, which brings malnutrition and at times disease. Dr. Hunt discusses history and current work on paleoclimatic environments as a potential model for understanding the multifactorial and interconnected nature of the impact of global warming. Learn why and what big-picture thinking is required.

Tracking Hannibal

Where did Hannibal lead 38,000 infantry, 8,000 cavalry, and 37 war elephants through the Alps in 218 BCE? The mystery of Hannibal's route has consumed archaeologist Patrick Hunt for over a decade. Hear about Dr. Hunt's quest for the route, using scientific, satellite imaging and historical materials, and his own hair-raising explorations of the Alpine passes.

PARTICLE PHYSICS

Speaker: Frank Linde, Ph.D.

Quantum Questions

Welcome to the world of the infinitely small and the weird phenomena that come with it, like slow-running clocks and anti-particles. Dr Linde leads us through the discoveries, concepts, and studies in the puzzling world of quantum mechanics in a session certain to spark your curiosity about the paradoxes and possibilities quantum physics poses.

Past and Present at CERN

To orient us to the Large Hadron Collider (LHC)'s significance, Dr. Linde recaps the highlights of CERN's "low energy" LEP accelerator which studied the Standard Model of particle physics. Learn how physicists think the LHC experiment will address current challenges in particle physics: the origin of particle masses; the mystery of dark matter and the apparent absence of antimatter in our everyday life.

Particle Physics Matters

What has particle physics done for you today? Dr. Linde discusses the societal benefits of his research. Learn how the particle physics field leads to the development of novel technologies and applications in medicine, information technology, energy, finance and commerce, and more. Find out how basic particle research, whose significance might not be obvious, touches on all our lives.

Astroparticle Physics

Parked at the intersection of particle physics, astronomy, and cosmology, astroparticle physics is evolving rapidly. Dr. Linde guides you through the strange terrain of astroparticle physics research rooted at CERN. Hear how deep-sea neutrino telescopes search for ripples in the space-time fabric itself and how huge cosmic-ray observatories are seeking answers to the big questions.

COGNITIVE NEUROSCIENCE

Speakers: Stephen Macknik, Ph.D. & Susana Martinez-Conde, Ph.D.

How the Brain Constructs the World We See

All our understandings of our life experiences are derived from brain processes, and are not necessarily the result of an event in the real world. Neuroscientists are researching the cerebral processes underlying perception to understand our experience of the universe. Discover how our brain constructs, not reconstructs, the world we see.

Windows on the Mind

What's the connection behind eye movements and subliminal thought? Join Drs. Macknik and Martinez-Conde in a look at the latest neurobiology behind microsaccades: involuntary eye movements that relate to perception and cognition. Learn how microsaccades suggest your 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 helps with cures for visual and neurological diseases. Connoisseurs of illusion, Drs. Macknik and Martinez-Conde produce the annual "Best Illusion of the Year Contest" . Study the most exciting novel illusions with them, and learn what makes these illusions work.

Sleights of Mind

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

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

PRIVATE, INSIDER'S TOUR OF CERN

April 20, 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 post-cruise, custom, full-day tour of this iconic facility.

Whether you lean toward concept or application there's much to pique your curiousity. Discover the excitement of fundamental research and get a behind-the-scenes, insider's look of 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.

This tour includes: • transfer from Basel (end of cruise) to our Geneva hotel (April 19) • hotel (3 nights) — the nights of April 19, April 20, and April 21 • full breakfasts (3) — April 20, 21, and 22 • transfer from hotel to CERN and back to the hotel on April 20 • lunch at CERN • cocktail party the evening after our visit to CERN (April 20) • free day in Geneva; transfers to/from downtown provided (April 21) • transfer to airport for return home (April 22)

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

INSIDER'S TOUR OF THE MPIA

Private tours of Max Planck Institute for Astronomy (MPIA) and the newly opened Center for Astronomy Education and Outreach on April 16, 2012 (mid-cruise) ($275 pp, includes elegant lunch)

We'll board a bus to Heidelberg right after breakfast. Our tour will include a visit to the Max Planck Institute for Astronomy, a presentation at the Center for Astronomy Education and Outreach including a planetarium show about the latest astronomical research done in Heidelberg, followed by a brief visit to the historical instruments of the Landessternwarte founded by Max Wolf in 1898. We'll conclude our excursion with a memorable lunch in downtown Heidelberg.

A FULL DAY IN AMSTERDAM

What makes Amsterdam a perennial favorite? InSight Cruises invites you to find out on a private, full-day tour of "the Venice of the North". Discover the unique charms of Amsterdam as you get oriented with a coach tour of cultural touchstones. Then anchor your vacation album with images from your cruise through the city's tree-lined UNESCO World Heritage canals, getting a superb view of 17th century gabled homes, old bridges, and bicycles and more bicycles. We focus on the finest, savoring an Old Dutch welcome and contemporary cuisine at one of Amsterdam's best restaurants, and then paint ourselves into the scene at the Rijksmuseum with a visit to "The Masterpieces" exhibit. Start your Bright Horizons memories and fun and join us! $275 pp.

SCIENTIFIC AMERICAN Travel

BRIGHT HORIZONS 14

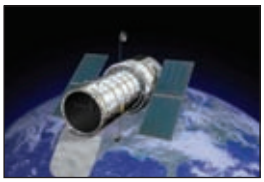
JUNE 8–15, 2012 ✸ ALASKA CRUISE ✸ www.InsightCruises.com/SciAm-14

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' Infinity, roundtrip Seattle June 8–15th, 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 first-hand 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 planetary science, cognitive science, particle physics, geospatial imaging, and space exploration. Please join us!

Cruise prices vary from $959 for an Interior Stateroom to $3,999 for a Royal Suite, per person. For those attending our program, there is a $1,475 fee. Government taxes and fees total $464.65 per person. Gratuities are $105 per person (a little more for Suite cabins). **For more info please call 650-787-5665 or email us at Concierge@InSightCruises.com**



STEPHEN P. MARAN, PH.D.

Galileo To Hubble and Beyond

How do Galileo's mind-blowing first telescopic discoveries contrast with current knowledge of the same celestial phenomena, examined with 21st century telescopes and space probes? Both Galileo and Hubble Space Telescope focus on centers of revolution, moons, planets, and rings, and galaxies. Find out how 17th and 21st century optical astronomy compare and relate.

Mystery Forces in the Solar System

Astronomers have investigated puzzles and discrepancies noted in the paths of moving bodies, and discovered previously unknown celestial objects and astrophysical phenomena. While each mystery solved is just a footnote in space discovery, together they demonstrate the unforeseen benefits of scientific exploration. Get the details with Stephen Maran.

Through Time and Space With the Hubble Space Telescope

What is the significance of the Hubble Space Telescope? Join Dr. Maran for a look at the whats and hows, highs and lows of the Hubble Space Telescope. The epic story spans vision, disaster, innovation, and outstanding discovery, much of which was unforeseen when the Hubble project began. Listen in on missions accomplished and new beginnings afoot.

Exoplanets and Life in Space

My, how things have changed! For years astronomers largely denied the existence of exoplanets. Now astronomers find planets wherever they look. Explore the stunning contributions of NASA's planet-hunting Kepler mission to the search for exoplanets and Goldilocks zones where life could exist. Join the discussion about the possibilities and implications.

STEVEN HAWLEY, PH.D.

The Legacies of the Space Shuttle

The Space Shuttle was technically, scientifically, and culturally transformational. Re-live the challenges, triumphs, and tragedies from 30 years of Space Shuttle operations from the perspective of a former astronaut and flight operations manager. Find out what China, Russia, and others are accomplishing in space, and explore potential directions for space exploration that may build on the Space Shuttle's legacies.

My Life with the Hubble Space Telescope (HST)

Dr. Steven Hawley was on hand when HST was deployed from Space Shuttle Discovery (STS-31), and on a record-setting Hubble maintenance mission (STS-82). Hear a first-hand account of how HST both revolutionized operations in Space and our understanding of the Universe. From robotic arms to eyes on the Universe, gain an astronomer-astronaut's unique perspective on Hubble's place in science and technology.

Astromaterials and the Space Environment

Astromaterials are particles, ranging from rocks to microscopic dust, originating in outer space. Learn how analysis of specimens in NASA's astromaterials collection (including cosmic dust, solar wind, comet particles, asteroids, and meteorites) improves our understanding of the solar system's origins and processes that may have contributed to the start of life on the Earth. We'll also learn about man-made components of the space environment and how they constitute hazards to spaceflight.

Mars and the Search for Life

Until 15 years ago, the odds for life on Mars seemed small. A Martian meteorite's suggestion of life rekindled interest; subsequent exploration hints at a hospitable environment. Is Mars even the best place to look for life in our solar system? Find out in a look at prospects for past or present life on Mars and other discoveries shaping the search for extraterrestrial life.

MURRAY FELSHER PH.D.

Observing a Changing World

Geospatial imaging scientists use an array of remote sensing technologies to image the Earth from Space. Gain a basic understanding and appreciation of how sensor technology now aboard earth-orbiting spacecraft provides data and information about planet Earth. Join Dr. Felsher in a program which will test your assumptions, expand your horizons, and pique your curiosity.

Topics include:

- Natural disaster monitoring, assessment, and mitigation: flood plain inundation, tsunami, earthquakes, and volcanic eruptions
- Renewable and non-renewable resource mapping: crop identification and yield, precision agriculture, and petroleum and mineral exploration
- Environmental applications: desertification and deforestation and oil spills
- Science applications: meteorology, oceanography, and hydrology
- Policy and political considerations: land use planning, coastal zone management
- "The View From Space: Planet Earth as an Artist's Palette", a look at terrestrial images from an aesthetic perspective


Dr. Steven Hawley

JAMES GILLIES, PH.D.

Particle Physics: Using Small Particles to Answer The Big Questions

Particle physics is the study of the smallest indivisible pieces of matter — and the forces that act between them. Join Dr. Gillies and catch up on the state of the art and challenges ahead as physicists continue a journey that started with Newton's description of gravity. We'll look at the masses of fundamental particles, dark matter, antimatter, and the nature of matter at the beginning time.

The Large Hadron Collider: the World's Most Complex Machine

The LHC is a machine of superlatives — a triumph of human ingenuity, possibly the most complex machine ever built. James Gillies traces particle physics technologies from the invention of particle accelerators in the 1920s to today, and then focuses on the LHC itself. You'll get a perspective on how these tools have allowed us to make phenomenal progress in understanding the Universe, and how they have revolutionized our everyday lives.

Angels, Demons, Black Holes, and Other Myths: Demystifying the LHC

Along with humankind's natural curiosity comes a fear of the unknown. As LHC's first beam day approached in 2008, a handful of self-proclaimed experts struck up an end-of-the-world tune — and the whole world knew they were there. Like its predecessors, the Large Electron-Positron Collider (LEP) and Relativistic Heavy Ion Collider (RHIC), the LHC never posed the slightest risk to humanity. However, the "dangerous scientist" has always made for a good story and that's something that Dan Brown exploited to the full when writing Angels and Demons. Dr. Gillies will cover the fact behind the fiction of Angels and Demons and black holes at the LHC, and share the behind-the-scenes on how CERN lived with the hype.

JOHN CACIOPPO, PH.D.

The Architecture of Human Affect and Emotion: Journeys in Evaluative Space

How can knowledge of the the neural mechanisms of emotions lead to better decision making? Dr. John Cacioppo presents studies of the affect system that provide a surprising perspective on human feelings and emotions. We'll look at the complex terrain between stimulus, evaluation, and human behavioral response, finding more questions than answers — great food for thought.

Human Nature and the Need for Social Connection: Loneliness and the Social Brain

Is it fundamental human nature to serve selfish interests, or those of others? Explore how selfish genes have sculpted innate capacities for social function. We'll talk about how loneliness evolved and relates to mental and physical well being. Learn about the complex work of social neuroscience and its implications for mind, behavior and health.

Why Do I Like the Things I Like? A Look Under the Hood of Attitudes and Persuasion

How can learning about how attitudes form and persuasion works lead you to make better decisions? Can cognitive science help you be more persuasive? Look under the hood of attitudes and persuasion and see that not all attitudes are created equal. Take home new insight on snap decisions, careful consideration, and why reasonable people may disagree.

Why Is Consciousness Epiphenomenal, Or is It?

Recent work in philosophy, psychology, psychiatry, and neuroscience questions the validity of the idea of human free will. Sort through provocative questions on consciousness, perception, thought, and behavior. We'll reflect on the legal and policy implications and gain an understanding of the mechanisms that orchestrate complex human behavior and behavioral flexibility.

SCIENTIFIC AMERICAN Travel HIGHLIGHTS

INSIDER'S TOUR OF THE MUSEUM OF FLIGHT

If you love vapor trails in the wild blue yonder and the thrill of take off, 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.

Lectures (60 minutes each):

Jet Propulsion and Jet Airplane Design Development

The design and development of the jet engine and the first airplanes to use them is an exciting and revealing story of personal determination in the face of bureaucratic and political obstacles before and during a World War. The remarkable transition from piston engined, straight winged airplanes to high speed swept wing jets is illustrated during this presentation. The skill and courage of the first pilots to probe the transonic speed region is summarized as a fascinating backdrop to what we take for granted as a part of modern life.

Carriers: Naval Aviation at Sea

The first attempt to take off from an aircraft carrier was in 1910, followed by a landing in 1911. This presentation will discuss the early development of aircraft carriers as well as catapults and arresting gear. Carriers played a significant role in the Pacific Theatre during World War II and in the ultimate success of the United States. Some of the most decisive carrier battles of the War will be discussed as well as what life is like aboard a "floating city".

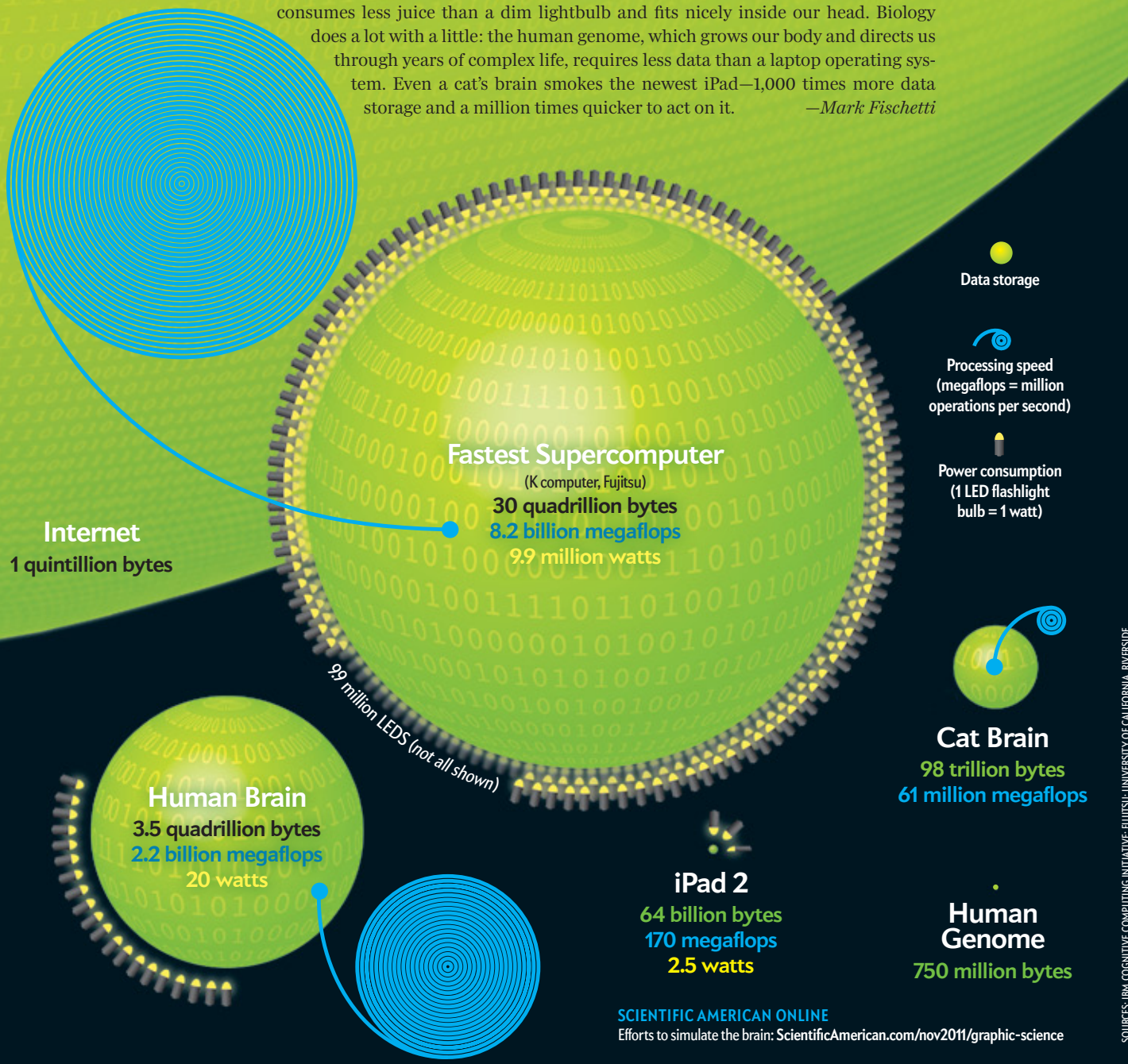
The price is $395 and includes all of the above (7 hours), an elegant lunch at The Museum of Flight, and roundtrip transfers to/from our Seattle hotel. This tour is limited to 25 people.

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

Computers vs. Brains

Computers are good at storage and speed, but brains maintain the efficiency lead

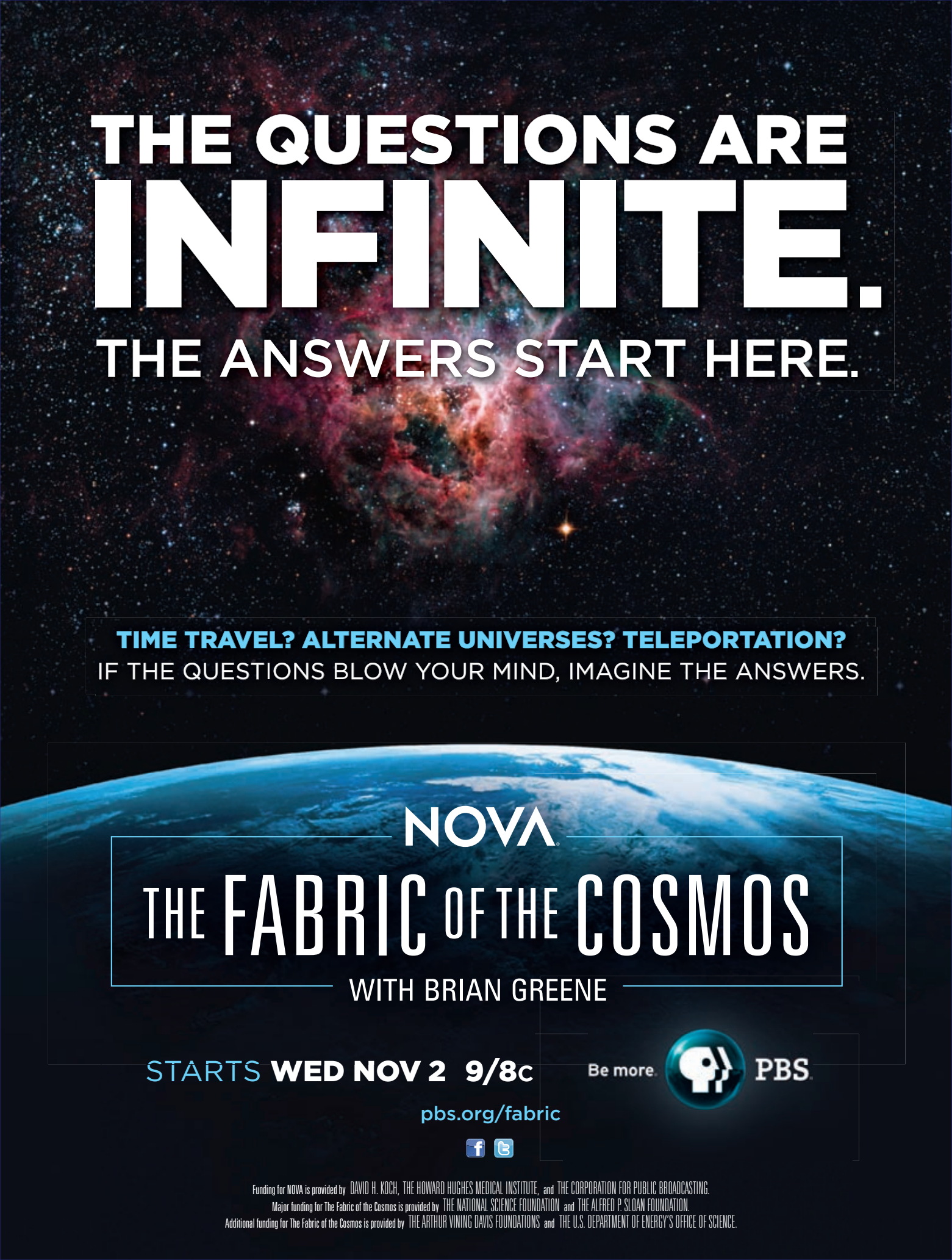
For decades computer scientists have strived to build machines that can calculate faster than the human brain and store more information. The contraptions have won. The world's most powerful supercomputer, the K from Fujitsu, computes four times faster and holds 10 times as much data. And of course, many more bits are coursing through the Internet at any moment. Yet the Internet's servers worldwide would fill a small city, and the K sucks up enough electricity to power 10,000 homes. The incredibly efficient brain consumes less juice than a dim lightbulb and fits nicely inside our head. Biology does a lot with a little: the human genome, which grows our body and directs us through years of complex life, requires less data than a laptop operating system. Even a cat's brain smokes the newest iPad—1,000 times more data storage and a million times quicker to act on it. *—Mark Fischetti*



SCIENTIFIC AMERICAN ONLINE
Efforts to simulate the brain: ScientificAmerican.com/nov2011/graphic-science

SOURCES: IBM COGNITIVE COMPUTING INITIATIVE; FUJITSU; UNIVERSITY OF CALIFORNIA, RIVERSIDE

Graphic by Jen Christiansen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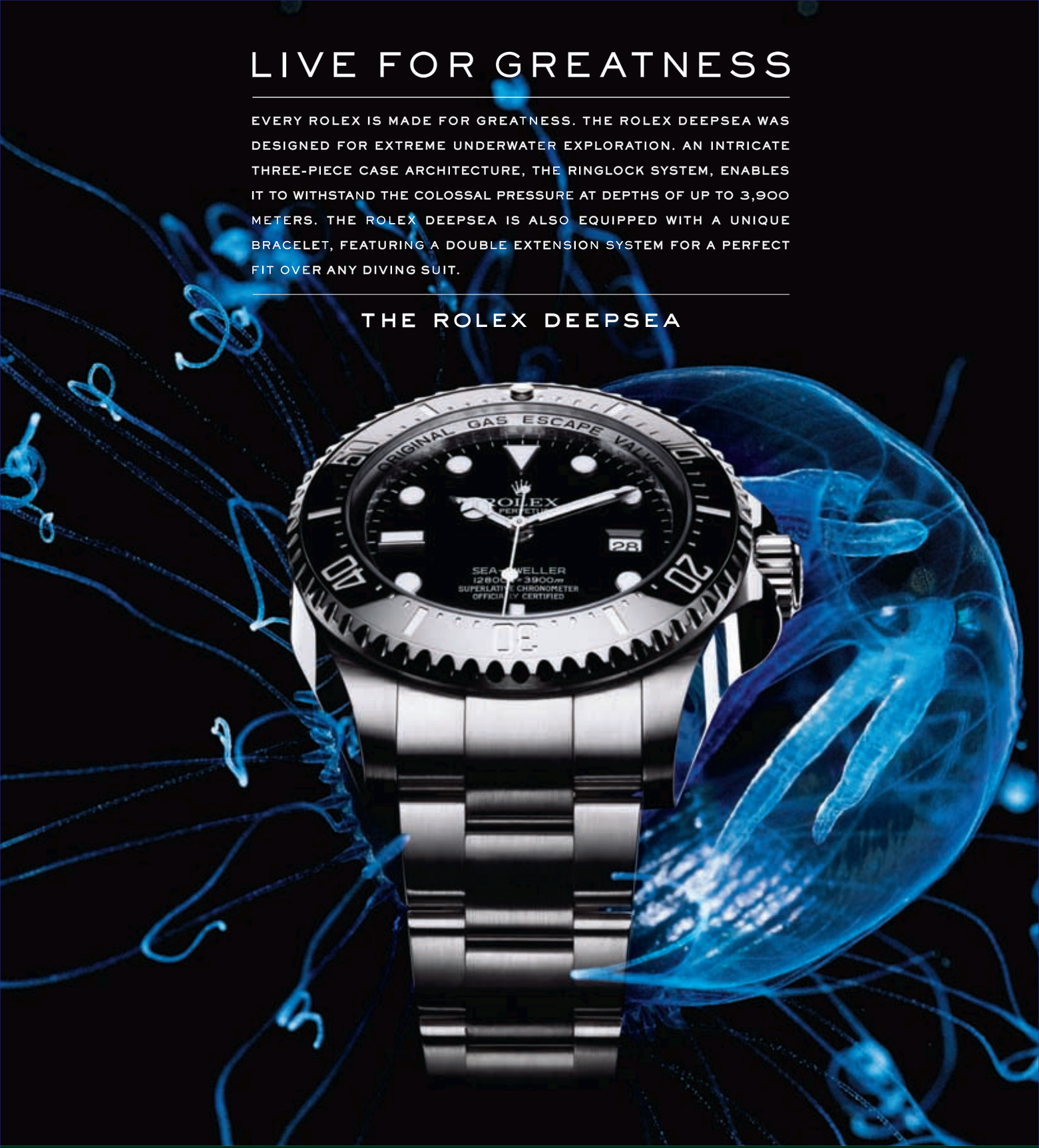

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