SCIENTIFIC AMERICAN

December 2010 ScientificAmerican.com

Anxiety
Psychedelic Cures

Dinosaurs
Blood from Stone

Physics
The Universe's Hidden Geometry

10 World Changing Ideas

Innovations for a brighter future

Robot Power Plants

Gas from Garbage

Better Living through Gaming

Nanotech Water Filters

The DNA Transistor

HOW A PLAN TO HELP A RENEWABLE ENERGY COMPANY GROW

ENDED UP CREATING MORE THAN JUST MEGAWATTS

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THIS IS HOW

The daily benefits of space exploration are all around us. GPS. ATM's. OMG–the list is endless! That's why Lockheed Martin eagerly supports math, science and engineering education for young people through K-12 mentoring. Inspiring the next generation to innovate next generation space technologies is all a question of how. And it is the how that Lockheed Martin delivers.

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SCIENTIFIC AMERICAN

December 2010 Volume 303, Number 6

ON THE COVER

This year's edition of World Changing Ideas explores the leading ways that technology and innovation can create a healthier, cleaner, smarter world, from biologically inspired algorithms to vegetarian robots to a cheap nanotech-based water filter.
Photograph by Mark Hooper.

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FEATURES

Photograph by David Liittschwager

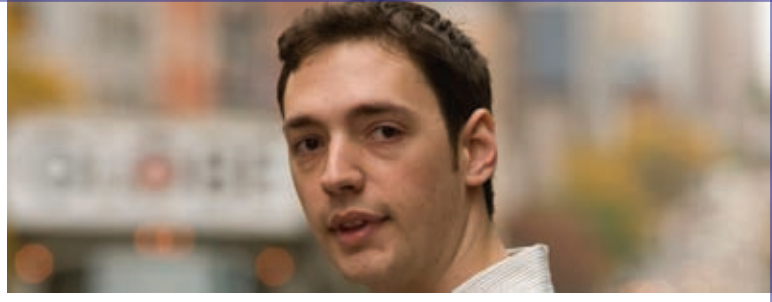
TRUST THE FUTURE TO THE YOUNG.

THEY HAVE LONGER TO LIVE IN IT.

For more than 30 years, the Rolex Awards for Enterprise have been an incubator for ground-breaking, world-changing ideas. This year is slightly different, although just as rewarding, thanks to an expansion of the Rolex Awards. Limiting entry to those aged 18 to 30 for the first time, the Young Laureates Programme has unearthed a rich, new seam of innovative thinking. The five winners all have a healthy dissatisfaction with the status quo and an infinite capacity to reinvent the world. These five outstanding Laureates each receive $50,000 to implement and expand their projects. And invent a better future for all of us in the process.

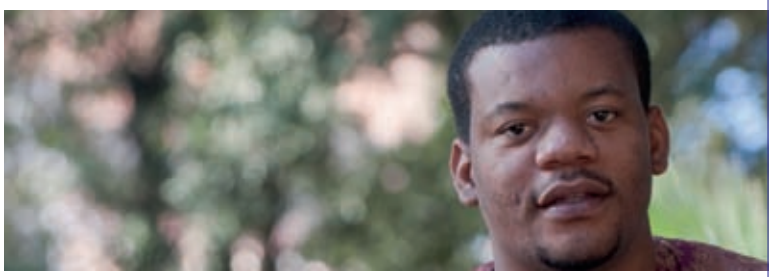
ROLEX AWARDS for ENTERPRISE
YOUNG LAUREATES PROGRAMME

YOUNG.ROLEXAWARDS.COM



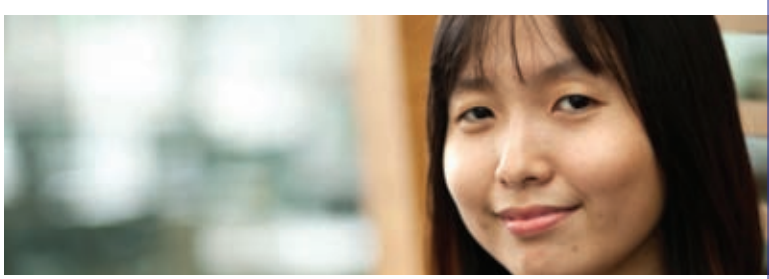
Jacob Colker – United States
Transforming volunteering for the 21st century

Bruktawit Tigabu – Ethiopia
Producing TV programs to improve children's health



Nnaemeka Ikegwuonu – Nigeria
Developing interactive radio to promote sustainable farming

Piyush Tewari – India
Training volunteers to provide rapid care to road accident victims



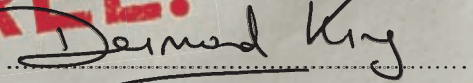
Reese Fernandez – Philippines
Enabling impoverished women to create eco-ethical fashion goods

ROLEX

IT'S TIME OIL COMPANIES GET BEHIND THE DEVELOPMENT OF RENEWABLE ENERGY.

WE AGREE.

Thomas Gideon
Executive Vice President, Timberlands
Weyerhaeuser Co.



Desmond King
President, Chevron Technology Ventures
Chevron

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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

Tour Seven Amazing Exoplanets
Astronomers are turning up exoplanets in droves, but what do these distant worlds look like? Hugo Award–winning artist Ron Miller interprets the data to give us a glimpse.
Go to www.ScientificAmerican.com/dec2010

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COURTESY OF NASA (rocket)

Smarter business for a Smarter Planet:

What 3 million lines of code means to a piece of luggage.

It means Amsterdam Airport Schiphol will be able to accurately and efficiently move 70 million pieces of luggage per year—20 million more bags per year than they used to. The airport's automated baggage solution will allow them to increase their baggage handling capacity by 40%, so they can meet the growing demand placed on them as one of Europe's largest transport hubs. This system is built on IBM Rational® and Tivoli® software and runs on Power Systems.™ A smarter business is built on smarter software, systems and services.

Let's build a smarter planet. ibm.com/luggage

A data visualization of the flow of baggage traffic at Amsterdam Airport Schiphol.

Mariette DiChristina is editor in chief of *Scientific American*.

Science That Matters

"Is what you're doing going to change the world?" asked Larry Page, Google's co-founder. "If not, maybe you should do something else."

I was at the annual Sci Foo Camp hosted by Nature Publishing Group (*Scientific American*'s parent), the O'Reilly Media Group and Google on its Mountain View, Calif., campus. At this "unconference," attendees—scientists and those with connections to science—created sessions on the spot, making for an energizing and freewheeling exchange over a weekend. But I have found myself reflecting most often on Page's words since.

Scientific American itself regularly features advances that can shape our future for the better, and we focus on a select list in the cover story, our second annual "World Changing Ideas." Among the 10 innovations are veggie-eating robots that produce electricity, a DNA transistor and bioinspired algorithms. In fact, threading through the section are two themes: managing information and benefiting from the use of biological models. Turn to page 42.

While I'm writing, I'd like to propose two more potential world changers. First, what if we stopped feeling frozen by uncertainties associated with climate change and—at least for starters—simply began applying good resources management within existing human experience? Water managers have to plan anyway for year-to-year variations—the 10-year flood, the 100-year drought, and so on—and it is not insurmountable to factor in additional adaptability when making infrastructure adjustments. I didn't make that up: I learned that lesson while moderating a panel of expert water managers during an all-day symposium on "The Climate Challenge" held by the Earth Institute's Columbia Climate Center and the Danish Consulate General. (Watch the panel video at www.earth.columbia.edu/videos/watch/260.)

Fun with science: Seventh graders got a sampling at a U.S. Science & Engineering Festival event.

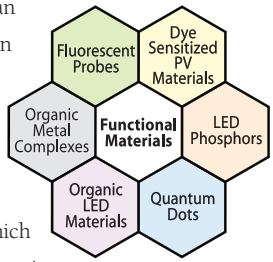
And here's another way to improve at least our corner of the world: What if U.S. culture finally started *admiring and participating* in science as an engine of our modern prosperity, instead of holding it on a pedestal apart? *Scientific American* recently served as a sponsor for the first national U.S. Science & Engineering Festival in Washington, D.C., and we've been media partners with the World Science Festival in New York City and others in the past. What if parents took kids to such festivals and museums as often as they went to ballgames or concerts? Maybe ultimately we could stop bemoaning the drop in science and math scores by U.S. students and our loss in global competitiveness, because we'd all appreciate those topics as much as we do fine literature, art and the latest action movie. I'd like to see us, in the near future, facing our problems by saying: "We'll have to science that." SA

Illustration by Nick Higgins

Advances in fluorescent spectrometry make it easier to tailor new functional materials...

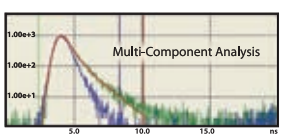
Higher-precision analysis, faster

Functional materials are unique substances that can sense environmental changes, such as temperature, pressure, electric fields, pH and much more. And by analyzing the fluorescent spectrum of such a material, a scientist can tailor its capabilities in many useful ways.



The problem is that a functional material may contain multiple elements, which confuses the spectroscopic analysis. So Hamamatsu created a solution...

Quantaurus is a new class of spectroscopic analyzers that can distinguish a material's component elements by measuring variations in the fluorescence lifetime, often at sub-nanosecond levels. Another Quantaurus model provides even more detail by measuring the absolute photoluminescence quantum yield.



Separating fluorescence lifetimes of components in a functional material.

All of these new analyzers are very fast. And very *automated*. Virtually anyone can use them. Making it easier to put more functionality into functional materials. For everything from solar cells to organic LED illumination, quantum dots to fluorescent proteins.

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Hamamatsu is opening the new frontiers of Light ✳✳✳

HAMAMATSU

Photon is Our Business

Hamamatsu's new Quantaurus series of advanced spectroscopic analyzers is able to measure variations in *fluorescence lifetime*, which is the length of time between a material's excitation by a light source and return to its ground state.

editors@sciam.com

August 2010

BLOWING THE WHISTLE

In "Danger in School Labs" [News Scan], Beryl Lieff Benderly lists four fatalities from lab accidents. She notes that the Protecting America's Workers Act would expand the jurisdiction of the Occupational Safety and Health Act of 1970 to include state employees, in particular those of state colleges and universities. Whistleblower protections would also improve. Sadly, 5,000 Americans die every year from workplace hazards. Sadder still, although dead bodies usually get Congress to pass better protections, opposition from the U.S. Chamber of Commerce has mired the bill in committees.

Under the 1970 act, whistleblowers can file a complaint with the Occupational Safety and Health Administration, but if OSHA decides not to take any further action in the case, the whistleblower has no further rights to any hearing or appeal. This dependence on OSHA has been devastating for the vast majority of workers who face retaliation after raising safety concerns.

In certain facilities, such as nuclear power plants, strong whistleblower protections already give workers in environmentally sensitive jobs meaningful legal remedies when they face retaliation for raising safety and compliance concerns. The new act would establish similar protections for all the employees OSHA covers in both the public and private sectors. When whistleblowers speak truth to power, they could finally hold employers accountable when they choose to retaliate. Our legislators need to know that lives are more important than Chamber of Commerce opposition.

"When whistleblowers speak truth to power, they could finally hold employers accountable."
RICHARD R. RENNER
NATIONAL WHISTLEBLOWERS CENTER

Richard R. Renner
Legal director
National Whistleblowers Center
Washington, D.C.

HUMAN BOTTLENECK

In "When the Sea Saved Humanity," Curtis W. Marean mentions that everyone alive today descended from a group of people from a single region who survived a cold, dry spell that went on between 195,000 and 123,000 years ago. But in the same issue, in Michael Shermer's Skeptic column "Our Neandertal Brethren," we learn that we are the descendants of a population of hominids that migrated into Europe some 400,000 years ago and another population from Africa that migrated between 80,000 and 50,000 years ago. How can one reconcile both theories?

Lionel Lecoq
Basel, Switzerland

MAREAN REPLIES: In my article I described how, between roughly 190,000 and 130,000 years ago, the modern human lineage (at that time restricted to Africa) was bottlenecked to a small breeding population, apparently during a strong glacial phase. When that glacial phase ameliorated at about 125,000 years ago, this small population expanded and spread throughout Africa. A subgroup of this expanding population eventually squeezed its way out of Africa into the Middle East, and from there those immigrants went on to Europe and East Asia.

As Shermer describes, Neandertal genome studies suggest that when this intrepid group of modern humans dispersed from Africa they encountered Neandertals in an intimate manner. The result was genetic leakage from the Neandertal line into the modern human genome, and this was carried throughout the non-African lineages and maintained, perhaps because it carried with it adaptive advantages. All modern humans descend from the small group that survived the bottleneck; however, in the case of people of European and Asian background, that lineage is not "pure," because our ancestors interbred with Neandertals. The Neandertal results highlight how scientists' strict definitions of fossil and living species do not always fit together well.

Marean describes his and his colleagues' investigation at Pinnacle Point, South Africa, and notes that the current vegetation of the region is highly diverse and includes a large number of species that are characterized by edible root tubers and bulbs, that is, geophytes.

The vegetation in any area on earth is dynamic, not static. It changes as the climate changes and as other factors that we do not understand change. Why, knowing the dynamic nature of vegetation, would one expect an abundance of geophytes so long ago?

Frank Reichenbacher
Scottsdale, Ariz.

MAREAN REPLIES: The presence of a geophyte plant part is often associated with an adaptation to hot, dry summers and arid climates, and that is the case for most of the geophytes in the Cape region, because the heartland of the Cape is dominated by winter rainfall. The entire Cape, including the fynbos and the interior Karoo, are superrich in geophyte diversity. Using other proxies such as large mammal fauna, micromammals and speleothems, we can confidently state that throughout the past 200,000 years the climates of the Cape were favorable to geophytes, even during maximum glacial conditions. In fact, the Cape was probably drier during glacials, and thus geophytes were even more favored than they are today.

SCIENCE AND FICTION

Michael Shermer's "Our Neandertal Brethren" [Skeptic] ends with, "Now that is a

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tale worthy of a romantic novel, brought to you by science." I believe this is exactly the plot of Jean M. Auel's 1980 novel *Clan of the Cave Bear*. Once again, science follows science fiction.

Rick Rantilla
Bluffton, S.C.

FAITH AND FOOLISHNESS

Thanks to Lawrence M. Krauss for writing "Faith and Foolishness" [Critical Mass] and thanks to the editors of *Scientific American* for publishing it. Many of us who agree wholeheartedly with what Krauss has to say are all too familiar with the wrath visited on nonbelievers by those who proclaim themselves believers in a religion of peace and love.

Dianne Wood
Halfway, Ore.

Krauss should be advised that most Americans who would describe themselves as Christian do not literally believe the world was created in six days a mere 6,000 years ago. Nor do any of the major Christian religions require their members to believe such a literal interpretation of the story of the origin of the world found in the Old Testament. Krauss's commentary seems more an attack on some religions than an attack on ignorance.

Rick Stager
Birchrunville, Pa.

ERRATA

Ronald Wallenfels, a historian at New York University, alerted us to a few inaccuracies in Brendan Borrell's "The First Humvee" [Origins]: "The Standard of Ur was certainly not a container; it may have been the decorated sound box of a large lyre. And its dimensions (20 by 47 centimeters) make it considerably larger than any ordinary 'shoebox,' unless of course, it held a pair of sandals belonging to Gilgamesh, the mythical semidivine king of Uruk. The animals drawing these wagons are not horses, which did not make their appearance in any significant numbers in the Near East until they arrived from Central Asia in the early second millennium B.C.; rather they are a type of wild ass. The 'poor foot soldiers … squirming to avoid [the] horses' hooves' are in fact dead enemy soldiers depicted nude as was the contemporary artistic convention."

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

Defying Politics

The laws of physics are the least of NASA's challenges

A crisis at NASA forces a new president to take action. A panel issues a report. The president gives a speech. He directs NASA to find a better way to get astronauts into orbit and to encourage private companies to enter the space taxi business. The plan promises to be the biggest shake-up of the space program since the glory days of the moon landings. Some embrace it; others take a dislike.

So it was with President George W. Bush's vision for NASA in 2004, which sought to rekindle the agency's exploratory spirit after the space shuttle *Columbia* disaster. The plan, though, fell apart when Bush failed to come through with the money to implement it. And so President Barack Obama came into office, found NASA in dire straits, commissioned a panel, led by aerospace veteran Norman Augustine, to work the problem, and made a big speech in April. How will the story end this time? Only strong presidential follow-through can keep NASA on course.

Obama proposed jettisoning much of the Constellation program, which Bush set up to build rockets and *Apollo*-like capsules to replace the space shuttle, and instead paying private companies such as Elon Musk's SpaceX to launch astronauts into orbit. He also relaxed Bush's deadlines to return to the moon, refocusing on what the Augustine commission called a "flexible path" of incrementally more difficult missions to asteroids and ultimately Mars [see "Jump-Starting the Orbital Economy," by David H. Freedman, on page 88].

For supporters of Constellation, the proposal was a call to arms. Even the reclusive Neil Armstrong came out to question it, and over the summer Congress tore it apart. The Senate agreed to a stripped-down version; the House of Representatives rejected it altogether. As an end-of-September fiscal deadline loomed, the House caved in and went along with the Senate.

Leaving aside the politics, the disagreement hinged on a genuine dilemma. Skeptics of the plan say that private companies are unproven. Proponents worry that keeping Constellation alive would be throwing good money after bad. Better to fund entrepreneurs who can drive down the cost of orbital launches.

Both sides have a point, but what tilts the balance in favor of Obama's plan is that we can't really "leave aside the politics." For Congress, NASA is not solely—or even primarily—a space agency. It is also a jobs agency, an industrial-policy agency and a foreign-policy agency. These ulterior motives keep getting in the way of good engineering. For instance, Obama had proposed undertaking basic technology development and only then deciding on the design for a new heavy-lift rocket, but the Senate insisted that NASA build the rocket with existing technology—which preserves jobs, even if it raises costs and hampers innovation in the long term.

The charm of Obama's plan is that it seeks to disentangle NASA from these vested interests. NASA will set the price and technical specifications of orbital launches and leave the details to private enterprise. It will be able to spread its eggs among many baskets rather than putting them in one. The plan thus fights the political pressures with the only force that might be more powerful: the profit motive. Space businesses have a strong incentive to buy equipment and hire people for their technical merit rather than because their congressional representative was able to bring home the bacon. That's one reason why Obama's plan met with so much opposition. Still, Congress ended up mostly going along with it—and that will help to let NASA be NASA.

Orbital: NASA may send astronauts aloft in commercially owned rockets like SpaceX's Falcon 9, which was test-fired in March.

COURTESY OF CHRIS THOMPSON *SpaceX*

Bush's plan failed for lack of follow-through, and if Obama's is not to do the same, he must keep pushing for more reforms. The first goal should be to fix the flaws in the plan that Congress has enacted, beginning with the lack of sufficient funds for technology development. If NASA were more consistent about investing in new technology, future missions could pull what they need off the shelf and would have a fighting chance of staying on budget. More broadly, Congress must find a way to give NASA some stability of funding and purpose. The Augustine commission pointed out that NASA has been hobbled by "recurring budget ambiguities" and congressional micromanagement. The agency needs greater autonomy, perhaps even a dedicated funding stream.

The specific plan—be it Bush's, Obama's or whoever's—doesn't matter. Where politicians have failed NASA is in not letting it do its job. Engineers will make mistakes, but engineers learn from their mistakes. It is time for politicians to do the same. SA

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/dec2010

GLOBAL HEALTH IS ABOUT OUR **LIVES**

A fresh and compelling look at one of the most pressing issues of our time…

The challenges of global health transcend the technical, scientific, political or financial. They are, in a sense, philosophical, requiring new ways of thinking, flexible ideologies and cooperation among a diverse range of stakeholders in an ever-shifting international environment with finite resources.

This magazine - brought to you by SCIENTIFIC AMERICAN - examines key themes from a multitude of perspectives and focuses on solutions.

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- Global Health through the eyes of the world's most vulnerable inhabitants
- Extreme water pollution
- Innovations in global health

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"When a man is healthy, he has many dreams; when he is sick, he has but one."

Commentary on science in the news from the experts

Hank Greely is Deane F. and Kate Edelman Johnson Professor of Law and professor of genetics at Stanford University. He specializes in ethical, legal and social issues arising from advances in the biosciences.

ANN CUTTING *Getty Images*

To Tell the Truth

Brain scans should not be used for lie detection unless their reliability is proven

Neuroscientists have been using brain scans to learn how to read minds. This research is increasing our basic understanding of the human brain and offering hope for medical breakthroughs. We should all applaud this work. Commercial firms, however, are beginning to apply this research to lie detection, selling their services. The technology is tempting, but before we accept it, we need to think hard about it—and go slow.

The trouble is not with the pace of research. Neuroscientists have been publishing articles about detecting lies with functional magnetic resonance imaging (fMRI) for nearly 10 years. About 25 published studies have found correlations between when experimental subjects were telling a lie and the pattern of blood flow in their brains. The trouble is that different studies, using different methods, have drawn conclusions based on the activity of different brain regions. And all the studies so far have taken place in the artificial environment of the laboratory, using people who knew they were taking part in an experiment and who were following instructions to lie. None of the studies examined lie detection in real-world situations. No government agency has found that this method works; no independent bodies have tested the approach. Yet people are buying lie-detection reports, wrapped in the glamour of science, to try to prove their honesty. In May two separate cases wound up in the courts.

One case hinged on whether the technology works. In a federal district court in Tennessee, the defendant in a Medicare fraud case wanted to introduce an fMRI lie-detection report into evidence to prove that he had not intended to commit fraud. After more than 12 hours of expert testimony, the judge concluded that the evidence should not be admitted. He found, correctly, that the accuracy of the method was unknown in real-world settings, that there were no standards for how the method should be applied, and that the scientific community did not generally accept this application of the technology.

The other case turned on the question of whether we should use the technology, even if it worked. The plaintiff in a state court civil case in Brooklyn, N.Y., wanted to introduce an fMRI report to show that her main witness was telling the truth. The judge in that case ruled that the credibility of a fact witness was solely a question for the jury; expert testimony about the witness's credibility was inadmissible, whether or not it was reliable.

These judges made good decisions, but tens of thousands of trial judges in America may have to rule on this technology, sometimes after hearing from good lawyers and expert witnesses and sometimes not. More important, millions of lives may be affected by the use of these lie-detection reports outside the courtroom—in criminal investigations, in business deals, perhaps in the military or the intelligence community, even in love and marriage.

Before the technology gets a foothold in society, we must answer, more broadly, the questions these judges confronted. We should ban nonresearch use of neuroimaging for lie detection until the method has been proved effective by rigorous, independent, scientific testing. Otherwise we risk hurting people and tarnishing the good name of neuroscience.

I don't know if fMRI will ever pass that test. If it does, when and how would we use it? Would we force defendants to submit to it? What about suspects, terrorists, misbehaving students, unruly passengers in airport security lines, or teenage children? Lie detection isn't the only mind-reading use of brain scans that the legal profession could use—scientists are working on detecting pain, biases and memories. We may ultimately decide to reject or accept these technologies. Either way, we must prepare for them. SA

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Courtesy NASA.

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96. Reflections on Life and the Cosmos

A day in the life: An artist's rendering of Gliese 581g.

ASTROBIOLOGY

Black Plants and Twilight Zones

Discoveries of distant planets are challenging theorists to think deeply about extraterrestrial life

Astronomers have long searched for a planet that could harbor life outside our solar system. When reports came in earlier this fall of the not too hot, not too cold exoplanet Gliese 581g, it was like the answer to a dream. "If it's confirmed, I think it's definitely the planet we've been waiting for, for a long time," says Rory Barnes, an astrobiologist at the University of Washington who wasn't involved in the research.

The wait may continue for a while. Soon after University of California, Santa Cruz, astronomer Steven Vogt and his collaborators reported the "Goldilocks" exoplanet, a rival Swiss group said it could not find evidence for Gliese 581g in its own data set. Confirming the new find, based on 11 years of subtle and indirect telescope-based measurements, could require several more years.

The tantalizing data, though, have already galvanized astronomers to step up their research on the conditions necessary for extraterrestrial life. The possibility that Gliese 581g may exist, they say, has added a new urgency for more sophisticated supercomputer models of life on other Earth-size planets.

Scientists, theoretical astrophysicists among them, combine astronomical observations with what they know about life on Earth to build simulations of exoplanet environments. Amid a recent surge of detected planets, realistic models could provide critical guidance for future missions seeking out signs of life in the universe. Recently Gliese 581g has become a focal point for this research. Its nearly circular orbit around a red dwarf star would position it at the optimal distance for temperatures permitting liquid water on the surface—an essential feature for life. The red dwarf, though, emits only 1 percent of the light from our sun. Photosynthetic organisms on the planet would likely absorb as much of the weaker starlight as possible, making them appear black, according to modeling by Nancy Kiang of the NASA Goddard Institute for Space Studies in New York City and collaborators at the University of Washington–based Virtual Planetary Laboratory.

Preliminary calculations also support the idea that one side of Gliese 581g always faces its star and roasts in temperatures up to 64 degrees Celsius, whereas the planet's dark side sees relentless North Pole–like winters. This positioning, still a matter of debate, might leave a more livable zone awash in a "perpetual sunset," as Vogt calls it. If such a hypothesis proves correct, Kiang says the specific wavelengths of light reaching each longitude could even prompt a rainbowlike gradient of plant colors with pigments adapted to absorb the light streaming across the surface.

Beyond energizing theorists, Gliese 581g has whet astronomers' appetites for what many expect to be hundreds of similar discoveries outside our solar system. "Either we've been very lucky and we won't find another one again for a long time," Vogt says, "or there's a lot of them out there." —*Bryn Nelson*

RON MILLER

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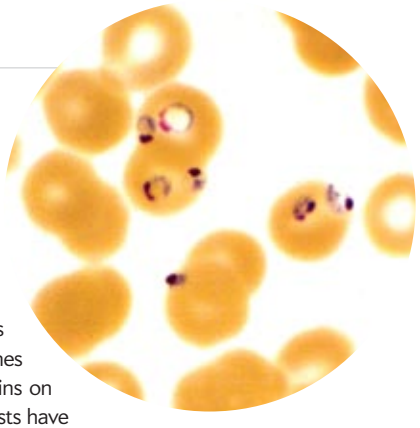
INFECTIOUS DISEASE

Pinning Down a Deadly Shape Shifter

A parasite's genome is yielding clues to how malaria kills



CECIL H. FOX *Photo Researchers, Inc.*

One step ahead: *P. falciparum* (*purple*) attacking red blood cells (*yellow*).

More people have died from malaria than from any other disease in history. If we look at the African parasite that causes its most severe form, it is obvious why the pathogen is so deadly. *Plasmodium falciparum* has a multistage life cycle and highly mutable genes. It's already widely resistant to one of the most common medications used to treat it, chloroquine, and it is starting to evolve around a newer drug, artemisinin. *Falciparum* is also a shape shifter, presenting different proteins on its surface as it develops in the body and remaining one step ahead of the immune system.

All this complexity is bad news for victims. But, in a sense, it may be good news for scientists, who sequenced the organism's genome in 2002 and are starting to figure out what malaria's intricate biology says about its natural history. Until recently, for instance, researchers thought *falciparum* had jumped into humans from chimps. But in September a team from Alabama—known for its work on the origin of HIV—showed that all *falciparum* parasites are descended from a single lineage that jumped from gorillas millions of years ago. Since then, the parasite has been furiously evolving. Drug resistance is part of that. But a much more important factor, according to researchers at the Broad Institute of M.I.T. and Harvard, is the human body itself. The malarial genes under the most intense selection pressure—those with the most variation, generated over a millennium-long cat-and-mouse game with the immune system's antibody response—are the ones that encode the identifying proteins on the surface of the parasite. Scientists have struggled to explain why some people get very sick from *falciparum*, whereas others suffer only mild symptoms; early work suggests that some of these "*var*" genes are behind serious cases in children.

One of the crucial next steps in understanding malaria's genome will be assessing how it differs from parasite to parasite and region to region. "Knowing the amount of variation within an individual is crucial," says Dominic Kwiatkowski, who leads malaria genomics research at the Wellcome Trust Sanger Institute near Cambridge, England. "Fortunately, we can quantify that with extraordinary precision." Kwiatkowski's group and others recently built MapSeq, an interactive database of genotyped samples from several hundred patients around the world. Researchers can use it to look for mutations unique to their areas—and to tailor their control strategies around them.

—*Mary Carmichael*

CHEMISTRY

The Incredible, Edible Foam

Mathematicians are still struggling to understand what happens atop your morning cappuccino

If you sometimes start your morning with a frothy cappuccino and finish off the evening with a heady glass of beer, then your day opens and closes with one of the most scientifically intriguing kinds of food: the edible foam. There are deep mathematical mysteries in these interlocked bubbles, and recently they have also become one of the most fertile areas for culinary innovation.

Top-ranked chef Ferran Adrià of elBulli in Catalonia, Spain, began experimenting with culinary foams in the mid-1990s in his quest to present diners with new and unexpected culinary experiences. Adrià used unconventional foaming agents such as gelatin or lecithin rather than eggs or cream. He used whipping siphons powered by pressurized nitrous oxide—much like cans of Reddi-wip but sturdier—to create ethereal foams from foods as diverse as cod, foie gras, mushrooms and potatoes. That started a revolution in foams, as chefs, among them Heston Blumenthal of Bray, England, New York City's Wylie Dufresne, and Chicago's Grant Achatz, have taken to foaming all manner of savory foods.

These dishes have an aura of mystique about them and not just for their novel texture. Although foams may look like random jumbles, the bubbles within all foams seem to self-organize to obey three universal rules first observed by Belgian physicist Joseph Plateau in 1873. These rules are simple to describe but have been remarkably hard to explain. The first rule is that whenever bubbles join, three film surfaces intersect at every edge. Not two; never four—always three. Second, each pair of intersecting films, once they have stabilized, forms an angle of exactly 120 degrees. Finally, wherever edges meet at a point, the edges always number exactly four, and the angle is always the inverse cosine of –⅓ (about 109.5 degrees).

Only a century later, in 1976, did Rutgers University mathematician Jean Taylor prove that, at least in the case of two joined bubbles, Plateau's rules derive from the action of surface tension, which forces the bubbles to adopt the most stable configuration. Mathematicians are still attempting to nail down exactly what happens in a froth of three or more bubbles, as well as the unsolved question of what arrangement of bubble shapes in a foam will fill a container while using the least surface area (and thus the least energy). In 1887 Lord Kelvin had proposed that a honeycomb of tetradecahedrons, each with six square and eight hexagonal faces, is the answer. But in 1994 physicists Dennis Weaire and Robert Phelan of Trinity College in Dublin published an even better—though not necessarily optimal—solution: a foam of two kinds of cells, one made solely from 12 pentagons and the other constructed from two hexagons and 10 pentagons.

In foamy foods, bubbles that do not follow Plateau's rules quickly pop. The same fate occurs to bubbles that are too small: surface tension raises the pressure inside them beyond the breaking point. That is one reason that liquid foams become coarser as they age—and why it is best to sip your cappuccino while it is fresh.

—W. Wayt Gibbs and Nathan Myhrvold

Myhrvold is author and Gibbs is editor of *Modernist Cuisine: The Art and Science of Cooking*, scheduled for publication in March 2011.

RYAN SMITH *Modernist Cuisine LLC*

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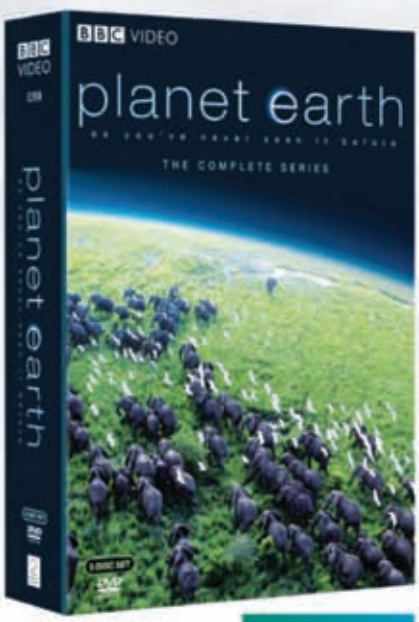

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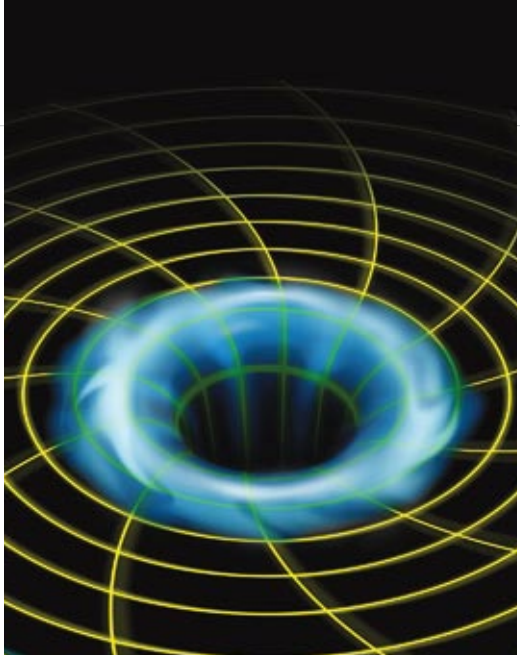
PHYSICS

Hawking Was Right (Probably)

Researchers may have re-created an elusive black hole phenomenon in the lab



In 1974 Stephen Hawking postulated that black holes should give off a trickle of particles, or radiation, from their outer boundaries. The finding established Hawking's reputation as a brilliant scientist and set the stage for his highly visible public profile, which includes provocative best-selling books and guest appearances on *The Simpsons*. In the midst of all the celebrity, the original theory of Hawking radiation, as the black hole phenomenon is known, has almost been forgotten, at least by the general public. The faint emission has never been detected from a real black hole, and researchers have not been able to produce the effect in the lab.

A few years ago a group of scientists in Italy decided to try a new approach to test Hawking's thesis. They used a piece of glass to re-create a black hole's "event horizon"—the point of no return beyond which even light is too slow to escape, where Hawking believes the radiation would arise. Alongside ordinary matter and light falling into a black hole, he reasoned, ought to be particles popping in and out of existence. Quantum mechanics dictates that such short-lived particle pairs arise even from empty space; in most corners of the cosmos, those pairs quickly disappear together back into the vacuum. But at an event horizon, one particle may be captured by the black hole, leaving the other free to escape as radiation.

Daniele Faccio of the University of Insubria and his colleagues created the event horizon in a section of fused silica glass, a medium in which intense laser pulses can locally perturb the speed at which light passes through the glass. That perturbation forms a moving event horizon, blocking photons from overtaking it. If a pair of photons is produced close enough to that event horizon, they will become separated and will be unable to return to the vacuum. The researchers recorded photons streaking outward from the glass, about one photon per 100 laser pulses, with all the traits they had predicted for Hawking radiation. They recently published their results in *Physical Review Letters*.

Physicists disagree about exactly what the observation means. Ulf Leonhardt of the University of St. Andrews in Scotland says the new research indeed represents the first observation of Hawking radiation. Others are not as sure. Theodore A. Jacobson of the University of Maryland says he is more convinced by another group's recent paper on a nonquantum analogue of Hawking radiation in flowing water. He points out that Faccio's group cannot verify that photons appear in pairs at the event horizon. "In our big piece of glass we have no way of saying where the other photon will end up," Faccio notes. But Leonhardt, who proposed the artificial event horizon scheme and is investigating the phenomenon in optical fibers, could detect both photons and show their common origin. "Once he does that, I think it will close all the discussions," Faccio says. —*John Matson*

MATT ZANG

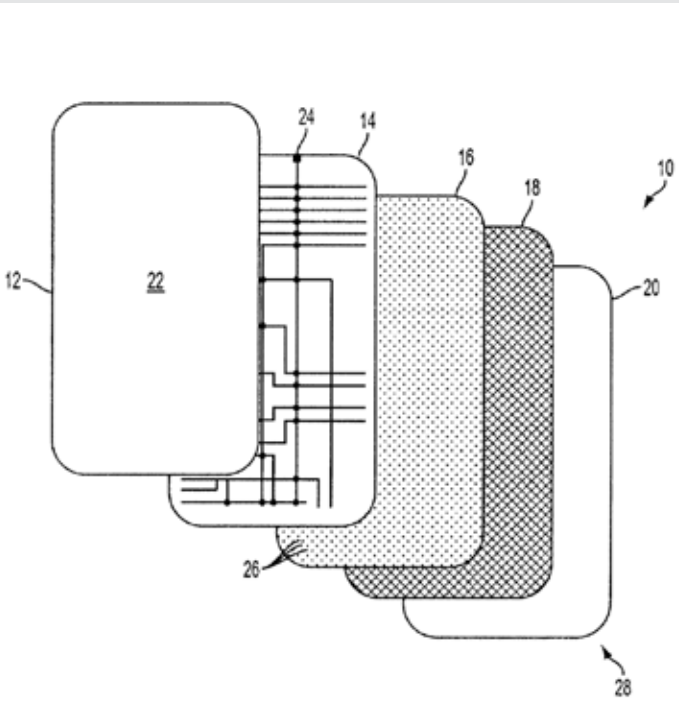
PATENT NO. 7,805,767

BODY ARMOR WITH BATTERIES

You'd never catch Iron Man *lugging around seven kinds of batteries. But that's exactly what U.S. Army squad leaders are required to do on 72-hour missions. The batteries, which can weigh a total of 16 pounds, are used to power radios, GPS systems and night-vision goggles. One of the goals of a newly patented variety of body armor, which has circuits and a power supply built into it, is to lighten the load that soldiers have to carry. "This is all part of a program leading to our own Iron Man," says Val Horvatich, a program director at BAE, which is based in Arlington, Va. He keeps a life-size cutout of the film and comic-book character in his office for inspiration.*

BAE's invention is one of the first to integrate electrical capabilities and a power supply directly into body armor. Horvatich says the built-in battery can power all the gadgets a soldier or police officer must carry, saving 20 to 60 percent of equipment weight. The new technology, which is scheduled for release in December, also has sensors and wireless capabilities that will automatically notify a soldier's team in the event of an attack.

Like an airplane that can continue flying with one damaged engine, the body armor is designed to function even if part of it is destroyed. A microprocessor built into the device will detect the hit and shut down the damaged quadrant but keep the others operational. "We call that 'graceful degradation,'" Horvatich says. He hopes this new armor will help troops enter and exit a field of battle the same way: gracefully. —Anna Kuchment



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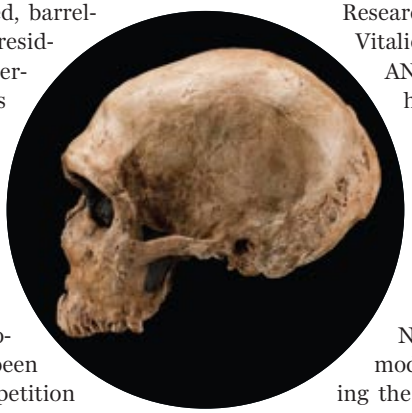
ARCHAEOLOGY

Out with a Bang

Volcanic eruptions may have wiped out the Neandertals

A cave in the northern Caucasus Mountains may hold a key to the long-standing mystery of why the Neandertals, our closest relatives, went extinct. For nearly 300,000 years the heavy-browed, barrel-chested Neandertals presided over Eurasia, weathering glacial conditions more severe than any our own kind has ever faced. Then, starting around 40,000 years ago, their numbers began to decline. Shortly after 28,000 years ago, they were gone. Paleoanthropologists have been debating whether competition with incoming modern humans or the onset of rapidly oscillating climate was to blame for their demise. But new findings suggest that catastrophic volcanic eruptions may have doomed the Neandertals—and paved the way for modern humans to take their place.



Researchers led by Liubov Vitaliena Golovanova of the ANO Laboratory of Prehistory in Saint Petersburg studied the deposits in Mezmaiskaya cave, located in southwestern Russia. First discovered by archaeologists in 1987, the cave once sheltered Neandertals and, later, modern humans. Analyzing the various stratigraphic layers, the scientists found layers of volcanic ash that, based on the geochemical composition of the ashes, they attribute to eruptions that occurred in the Caucasus region around 40,000 years ago. Because the cave preserves a long record of Neandertal occupation preceding the ash layers but no traces of them afterward, the team surmises that the eruptions devastated the locals.

Moreover, looking more broadly at sites across Eurasia, the investigators noted that the eruptions coincided with the disappearance of the Neandertals across most of their range, save for a few groups that took refuge in the south. In a paper published in *Current Anthropology,* they propose that the eruptions precipitated a so-called volcanic winter that may have resulted in mass deaths of Neandertals and their prey. The misfortune of the Neandertals, however, was a boon for modern humans, who lived in southern locales unaffected by the volcanic activity. Once the Neandertals were gone, so the theory goes, moderns could move north unchallenged.

The team's interpretation of the data from the cave has elicited criticism from some researchers, such as Francesco G. Fedele of the University of Naples in Italy, who complained in commentaries published alongside the paper that the age of the ashes is not firm enough to draw such conclusions. But others, including Paul B. Pettitt of the University of Sheffield in England, called the new extinction and replacement scenario plausible. The riddle of the Neandertals' downfall is far from solved, but the volcanic eruption theory may turn up the heat on the competition. —*Kate Wong*

QUOTABLE

"... even if we kicked you in the pants it was between friends."

—Francis Crick in a newly uncovered 1951 letter to Maurice Wilkins. The two shared a 1962 Nobel Prize with James Watson for showing that DNA forms a double helix.

CHIP CLARK *Human Origins Program, Smithsonian Institution*

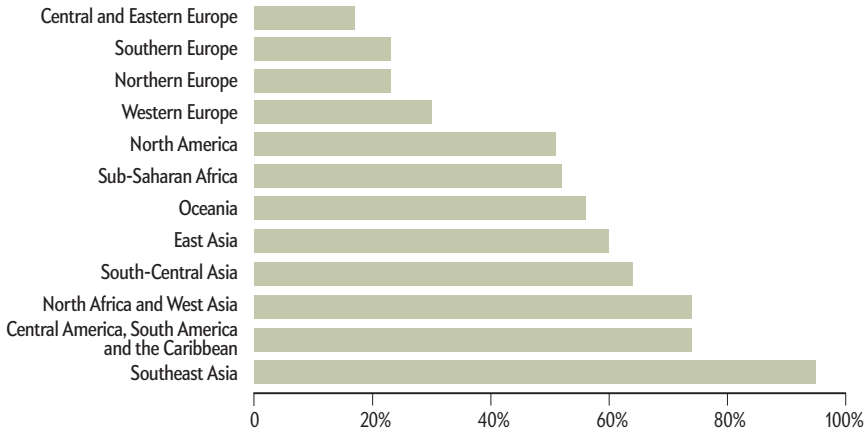
WHAT IS IT?

Preppy in Papua: *This pink-and-green katydid, a large grasshopper, is one of 200 new species that scientists recently discovered in Papua New Guinea. About three inches long, it lives in the forest canopy of the rugged Muller Range in the central-western part of the country. Harvard University's Piotr Naskrecki, who found the katydid on an expedition for Conservation International, says it probably evolved its pink eyes as a form of camouflage. "Leaves in tropical forests are often dotted with fungi and epiphytes [plants that grow on other plants]," he says.*

"Although these eyes may look striking to us, when the katydid sits motionless, they help with the illusion that it is just a leaf." Fortunately, they didn't fool Naskrecki. —Anna Kuchment

COURTESY OF PIOTR NASKRECKI

Projected percent increase in deaths caused by cancer (2002–2020)



SOURCE FOR CHART: WORLD HEALTH ORGANIZATION AND INTERNATIONAL UNION AGAINST CANCER

PUBLIC HEALTH

A Global Call to Action on Chronic Diseases

Most deaths from cancer and heart disease now occur in the poorer parts of the world

The global health community has won many victories against infectious disease in the poorer parts of the world—eradicating smallpox in the 1970s and beating down the number of reported polio cases. Now it is turning to cancer and heart disease. The Institute of Medicine (IOM) in Washington, D.C., recently released a report warning that the rising tide of cardiovascular disease in low- and middle-income countries is threatening those nations' economic well-being. And a group of physicians and celebrities (including cycling champion Lance Armstrong and Princess Dina of Jordan) has published a call to action in *Lancet* to expand cancer care and control in poorer countries.

The renewed attention reflects major changes in disease trends. Cancer and heart disease are not limited to developed countries. According to the International Agency for Research on Cancer in Lyon, France, more than half of all people who were newly diagnosed with cancer in 2008 were in developing countries such as Nigeria, Egypt and Brazil—compared with just 15 percent in 1970. The IOM's 2010 study reported that 80 percent of deaths from heart attacks, stroke and other cardiovascular diseases around the world now occur in the developing world.

In some respects, the rising proportion of cancer cases is a side effect of success. People are living longer (cancer is more common the older you get), and fewer people are dying of infectious diseases (you have to die of something). Similarly, the increase in cardiovascular disease is linked to aging populations, but adopting a Western-style diet and getting less exercise also play important roles. Treating cancer in the poorest parts of the world is not necessarily expensive; many older treatments that Westerners have replaced with pricey ones are still highly effective. The same is true for treating heart disease. Unfortunately, the older medications are often not broadly available in poor countries, and physicians, nurses and other health care workers are often lacking. *—Christine Gorman*

QUOTABLE

"Carbon, the basis of all known life on earth, has surprised us once again."

—The Royal Swedish Academy of Sciences in a statement awarding the 2010 Nobel Prize in Physics to the discoverers of graphene, one of the thinnest yet strongest materials on the planet.

Graphic by Jen Christiansen

EDUCATION

Dear Santa: Please Send Owl Puke

SA asked scientists to recommend their favorite educational gifts for kids

1. Geomag magnetic building set *From $11 at reevesintl.com; ages 3 and up.* William Shih of Harvard University's Wyss Institute for Biologically Inspired Engineering suggests discussing with kids what makes some structures (such as a cube) less stable than others (a tetrahedron).

2. Galileoscope *$30 at galileoscope.org; all ages.* Cameron Hummels, a Ph.D. candidate in astronomy at Columbia University and head of outreach for the department, says that these are by far the best-quality telescopes for the price. "Because they're so inexpensive, they don't come with a tripod, so I'd recommend getting a cheap camera tripod—the taller the better. Also, download some free sky-visualization software for identifying astronomical targets" (www.stellarium.org).

3. Snap Circuits *From $31.95 at elenco.com; ages 8 and up.* Chris Gerdes, a Stanford University mechanical engineer, says: "Snap Circuits have been hugely popular in my house. These are snap-together circuits on pieces that resemble electrical schematics. Kids read the schematic, build a circuit that looks exactly like it, and make something cool like an alarm, a variable-speed motor drive or a sci-fi sound-effect generator."

4. Unreal Upchuck pellets *$14.48 at fatbraintoys.com; ages 8 and up.* Owls swallow their prey whole, then regurgitate the bones, fur and feathers. Owl pellet kits let kids dissect an owl's puke—er, leftovers—and reconstruct the animal skeletons inside. Some, like Unreal Upchuck, use synthetic pellets; others use real ones that have been heat-sterilized. Says Kent Kirshenbaum, a professor of chemistry at New York University: "Biology can be a bit icky. I think that is part of what makes it exciting!"

5. *Biology: Life As We Know It!, The Periodic Table: Elements with Style!* and other Simon Basher books in this series from Kingfisher *(Kingfisher and Scientific American are part of Macmillan Publishers). $8.99 at Amazon.com; ages 10 and up.* Recommended by Jim Collins of Harvard's Wyss Institute for Biologically Inspired Engineering.

6. Murderous Maths book series, *by Kjartan Poskitt (Scholastic UK) $7.67 each at horriblebooks.com; ages 9 and up.* Stacey F. Bent, a professor of chemical engineering at Stanford, says that the books provide "very humorous and engaging introductions to topics such as algebra, geometry and probability." —*Anna Kuchment*

Photograph by James Worrell

SCIENTIST IN THE FIELD

Know the Flow

The engineer and recent MacArthur "genius" grant winner thinks we have much to learn from the humble jellyfish

What do you do every day? Quite a few different things. On a given day we could be working on wind energy or working with the navy on underwater vehicles. We have, in our laboratory, live jellyfish in the upstairs labs and, downstairs, robotic vehicles that we design. We study biological systems and try to steal ideas from nature to apply to technology.

Does the navy want a submarine that looks like a jellyfish? Our designs don't look like robotic jellyfish per se. We take the existing platforms that the navy uses—the propeller-driven vehicles—and try to modify them to create the flows that we see in jellyfish.

Something like putting a spoiler on the back of a race car? That's probably a good analogy—one of these things that modify an existing system to enhance its performance. Certainly we could imagine building things that were more like jellyfish or squid in their nature. But what we're really waiting for is for the materials scientists to come up with something that provides the flexibility that you would want and at the same time has the strength and the resilience that you would expect from a vehicle that's going to be in the water for many years at a time.

You recently showed that studies of fish schooling can aid wind-farm design. How does that work? The challenge with existing horizontal-axis wind turbines is that they need a lot of space; you have to separate the turbines so that their wakes don't interact. So we started to explore vertical-axis wind turbines, which rotate on a vertical pole and can take wind from any direction. As I was starting to model the equations for the wind field around a turbine, it was sort of one of these eureka moments—I realized that they were very similar to the equations that we saw previously studying fish schooling. Fish arrange themselves to *minimize* the amount of energy that's required for the group to go from point A to point B. Our aim would be to try to *maximize* the amount of energy that is extracted from these vertical-axis turbines.

PROFILE

NAME
John Dabiri

TITLE
Associate professor of aeronautics and bioengineering, California Institute of Technology
2010 MacArthur fellow

LOCATION
Pasadena, Calif.

So in your model, you are able to get 10 times higher energy density? Not just in our models. Over this past summer we have done small field tests, and the predictions of the model have been borne out.

Sounds like you've got your first business. [Laughs] I think what we're really aiming to do is to change people's minds about wind energy. People call it the most mature of the renewable energy technologies, where the future is: Can we build them larger? Can we put them offshore? But there are some fundamental advances that can be made if we reconsider whether the three-bladed turbine is the optimal solution.

If everyone could know one thing about your work, what would it be? Technology is ever evolving. While there's a lot of opposition to the current platform for wind energy, there are better options to come. There's no need to settle just yet.

—Michael Moyer

COURTESY OF THE JOHN D. AND CATHERINE T. MACARTHUR FOUNDATION

DO THE MATH

The Science of "Disestimation"

Why we shouldn't put our faith in opinion polls

At the end of September the Pew Forum on Religion and Public Life released a survey that seemed to show that nonbelievers knew more about religion than the faithful. Some media outlets crowed about the results ("Atheists Know More about Religion Than Believers," *Time* magazine declared), whereas others turned to comforting the faithful ("We Didn't Flunk the Religion Test," *FoxNews.com* insisted). Few seemed to realize that the polls were far from immaculate. In fact, the episode was a good example of what I call disestimation: the act of taking fuzzy numbers way too seriously.

At first, it might seem like a cut-and-dried story: out of 32 quiz questions, atheists and agnostics, on average, got 20.9 correct, higher than any other group and higher than the overall average of 16.0 questions right. But because Pew managed to reach very few atheists and agnostics—only 212 people out of the 3,412 included in the survey—the 20.9 number masks a tremendous amount of imprecision. Small samples don't give reliable numbers, and if you present the poll results using a standard graphical technique to represent uncertainty (*below*), you can see that the distinction between atheists/agnostics and Jews and Mormons evaporates.

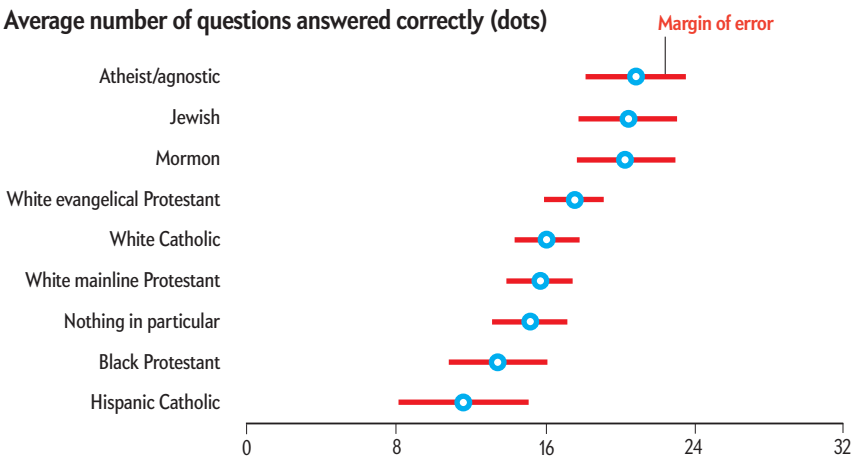
The story gets even fuzzier because Pew left out one category altogether: those who believe "nothing in particular," many of whom had specifically said they didn't believe in God. Interestingly, this group scored worse than the typical American on the religion quiz. Had they been lumped together with atheists and agnostics, the group would have fared a little worse, on average, than evangelical Protestants.

When Pew did a more stringent analysis, correcting for respondents' education and income (which, sadly, was buried deep in the report), there was no significant difference between believers and nonbelievers. Those who said they did not believe in God scored a mere 0.3 point higher than the national average, a meaningless number, given how big the error bars are.

The press leaped on the atheists versus believers headlines without critically examining the numbers. The Pew study revealed less about our faith in God than it did about our faith in polls—which, far too often, is blind.

—*Charles Seife*

Seife is author of *Proofiness: The Dark Arts of Mathematical Deception* and a professor of journalism at New York University.



SOURCE FOR CHART: PEW FORUM ON RELIGION AND PUBLIC LIFE

QUOTABLE

"We know the mountain is large, but we are small."

—Swiss Environment and Transport Minister Moritz Leuenberger after engineers completed the world's longest tunnel, a 57-kilometer future rail line, under the Alps.

Graphic by Jen Christiansen

TECHNOLOGY

A Click of the Tongue

Linguists have found a new application for ultrasound—decoding dying languages

Amanda Miller sits facing an old woman in Upington, South Africa, one hand on a cylindrical probe that she holds underneath the woman's chin. "Speak," Miller says in the woman's native language, N|uu, and as the words flow out, an ultrasound screen flickers with the video of a tongue in motion. Linguists are using the same technology that images fetuses to study endangered languages.

For someone who studies phonetics—the science of how sounds are perceived, articulated and organized in different languages—it is crucial for Miller to track the speaking tongue. Miller is a visiting assistant professor at Ohio State University and one of about 40 linguists worldwide who uses ultrasound. This portable technology, which became affordable to linguists around 2000, allows researchers to see the tongue as it moves in real time. It is one of the only medical scanning devices that can keep up with speech; MRIs, for example, are too slow.

Before ultrasound, linguists relied on x-rays and glue-on electronic probes. The x-rays failed because they exposed subjects to harmful radiation, whereas the probes were often inconvenient. "You can imagine if you walk into a village and say, 'Look, people, all I want to do is blow-dry your tongue and glue things to it,' people might be a little nervous," says Diana Archangeli, a linguistics professor at the University of Arizona who has worked with ultrasound since 2004.

Thanks to this emerging technology, Miller and her colleagues have documented some of the fastest sounds in human speech: the click consonants present in many rare African languages.

Because linguists did not know exactly how the clicks were produced, the sound was placed in a "mixed-bag" category of the International Phonetic Alphabet, a universal system that catalogues all the sounds in the world's languages. Linguists use this alphabet to study the relation between different sounds and, through that, the origins of people and languages.

Miller has investigated more than 40 different kinds of click consonants. Her research, published in 2009, organized the clicks based on attributes such as airstream (where the air comes from), place (where the mouth constricts) and manner of articulation. These changes have allowed the clicks to be properly classified into the alphabet. "Once you have the [clicks' classifications and] subclassifications, you can begin to see similarities … to other sounds in English, for example," Miller says. Both "t" and "k" share some characteristics of click consonants.

Elsewhere, other linguists are using ultrasound to teach foreign languages and help the deaf to speak. As for Miller, she will continue to study endangered languages, seeking to integrate new sounds into the International Phonetic Alphabet.

—Lisa Song

NEWS SCAN

Genius

U.S. doctors begin first human trial of embryonic stem cells on paralyzed patient in Atlanta

Nissan reaches 20,000-order goal for its all-electric car ahead of schedule, despite the Leaf's limited (100-mile) range

Scientists think they have solved the disappearing-bees puzzle: a fungus and virus combination that is treatable

Obama to install solar panels on White House roof, prompting unflattering comparisons to Carter

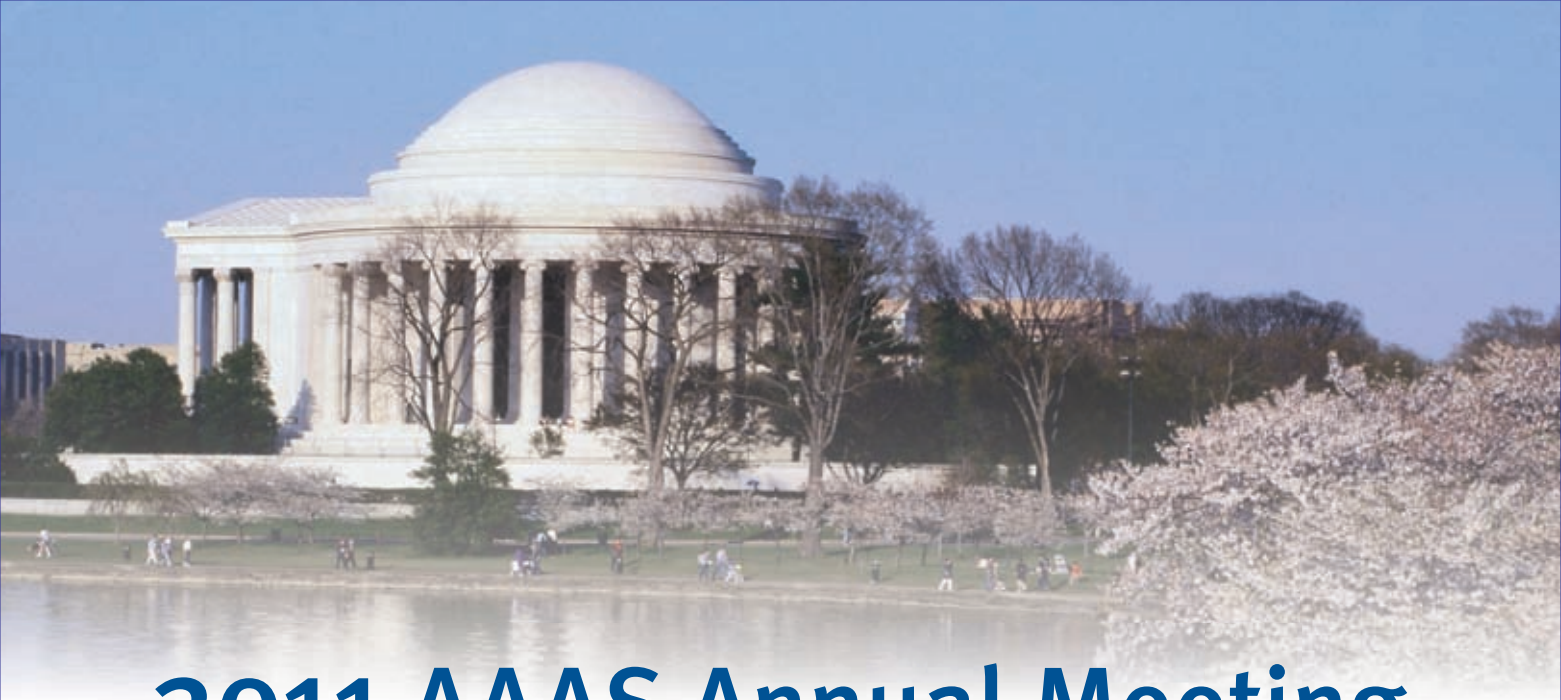
Accident at factory in Hungary sends millions of gallons of toxic red sludge through villages and into the Danube

U.S. apologizes for intentionally infecting Guatemalans with venereal diseases in the 1940s during penicillin testing

Folly

—George Hackett

COURTESY OF NISSAN (*car*); MICHAEL DURHAM *Getty Images* (*honeybee*); CHARLES DHARAPAK *AP Photo* (*White House*); BALAZS MOHAI *AP Photo* (*sludge*)



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Accelerating Enterprise Transformation with Architecture-Driven Modernization

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.


Above: Eurocat control station

Early software translations of the 1990s, like the earliest chess programs, were disappointing and limited. Leveraging AI technologies that evolved from the 1980s era USAF's Knowledge Based Software Assistant (KBSA) 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 finance, healthcare, military, and governments modernize 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.

Many groundbreaking TSRI projects are documented in the OMG Series book aptly titled, Information Systems Transformation: Architecture Driven Modernization Case Studies by William Ulrich and Philip Newcomb (TSRI's founder), Morgan-Kauffman, 2010. This book is a compelling 'How To' guide for conducting modernization projects, a few examples of which are listed below:

- **Eurocat - European Air Traffic Management System for Thales Air Systems:** 2+ million lines of Ada into Java, being deployed to 280 airports.
- **Advanced Field Artillery Tactical Data System, U.S. Army and Stanley Techrizon :** 7+ million lines of Ada into Java, completed in 10 months.
- **Patriot Missile - Fire Platoon Simulation & Battalion Simulation Support Systems for Raytheon:** 600 thousand lines of FORTRAN into C++.
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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 to update costly obsolete systems, transform data, and save millions of dollars.

Philip Newcomb
Founder and CEO of TSRI

Mr. Newcomb is an internationally recognized exert in the application of AI and formal methods to software engineering. After leaving Boeing he led a team of software engineers to develop TSRI's JANUS Studio® toolset. Mr. Newcomb is the author of numerous papers, books and industry standards.

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

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the software revolution, inc.

Christine Gorman is an award-winning science journalist who has covered health and medical topics for more than 20 years.

The Heart-Brain Connection

Could exercising regularly and not smoking help to delay dementia?

When the National Institutes of Health convened a panel of independent experts this past April on how to prevent Alzheimer's disease, the conclusions were pretty grim. The panel determined that "no evidence of even moderate scientific quality" links anything—from herbal or nutritional supplements to prescription medications to social, economic or environmental conditions—with the slightest decrease in the risk of developing Alzheimer's. Furthermore, the committee argued, there is little credible evidence that you can do anything to delay the kinds of memory problems that are often associated with aging. The researchers' conclusions made headlines around the world and struck a blow at the many purveyors of "brain boosters," "memory enhancers" and "cognitive-training software" that advertise their wares on the Web and on television. One of the panel experts later told reporters in a conference call that the group wanted to "dissuade folks from spending extraordinary amounts of money on stuff that doesn't work."

But did the panel overstate its case? Some memory and cognition researchers privately grumbled that the conclusions were too negative—particularly with respect to the potential benefits of not smoking, treating high blood pressure and engaging in physical activity. In late September the *British Journal of Sports Medicine* published a few of these criticisms. As a longtime science journalist, I suspected that this is the kind of instructive controversy—with top-level people taking opposing positions—that often occurs at the leading edge of research. As I spoke with various researchers, I realized that the disagreements signaled newly emerging views of how the brain ages. Investigators are exploring whether they need to look beyond the brain to the heart to understand what happens to nerve cells over the course of decades. In the process, they are uncovering new roles for the cardiovascular system, including ones that go beyond supplying the brain with plenty of oxygen-rich blood. The findings could suggest useful avenues for delaying dementia or less severe memory problems.

Dementia, of course, is a complex biological phenomenon. Although Alzheimer's is the most common cause of dementia in older adults, it is not the only cause. Other conditions can contribute to dementia as well, says Eric B. Larson, executive director of the Group Health Research Institute in Seattle. For example, physicians have long known that suffering a stroke, in which blood flow to the brain has been interrupted by a clot or a hemorrhage, can lead to dementia. But research over the past few years has documented the importance of very tiny strokes—strokes so small they can be detected only under a microscope after death—as another possible cause for dementia. Studies at autopsy of people who had dementia have detected many of these so-called microvascular infarcts either by themselves or along with the plaques and tangles more typical of Alzheimer's in the brains of people with dementia. These findings suggest that most dementias, even those caused by Alzheimer's, are triggered by multiple pathological processes and will require more than one treatment.

Proving that cardiovascular treatment is one of those approaches will take some doing. Just because microinfarcts may

Illustration by Ross MacDonald

Bright Horizons™ 9

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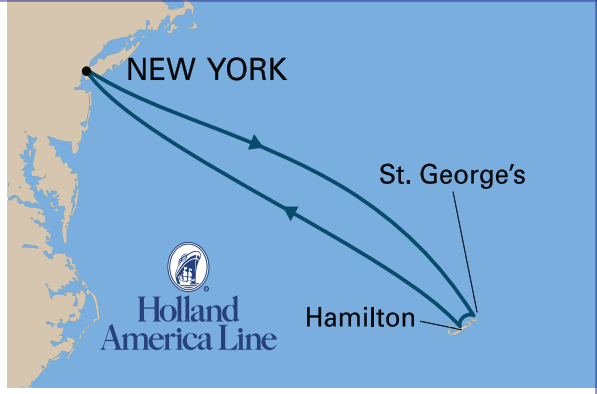

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Updated on Bright Horizons 9, you'll bring a breath of rational fresh air to discussions of evolution, the paranormal, and urban legends. Make waves with a look at gender and the brain. Examine how virtual reality impacts face-to-face life. Satisfy your curiosity about the persistent appeal of extra dimensions. Fill in the blanks in Colonial American archaeology and cultural anthropology with a discerning look at Florida and the southeastern United States.

Start your version of Bright Horizons 9 off with an optional visit to NYC's Rose Center/Hayden Planetarium. Then, set sail and let Bermuda bring you a smile with its unique and very British take on the idiosyncrasies and pleasures of island life. Play a little golf, visit a fort, take tea. Visit InSightCruises.com/SciAm-9 or call Neil or Theresa at 650-787-5665 to get all the details. Prepare to simultaneously kick back, and sharpen your science sense on Bright Horizons 9.

SCIENCE IN NEW YORK CITY

Saturday, May 7, 2011 (optional)

Wake up in the city that never sleeps, as we start at 9am in the Rose Center for Earth and Space (below) at the American Museum of Natural History for a private insiders' tour. During our tour we'll get the inside scoop on research being done at the Rose Center. After our astronomy sojourn, we'll reconvene in lower mid-town Manhattan, at the Scientific American headquarters, for an early evening social reception/dinner with Scientific American staffers.

During our visit, the Curator of the Einstein exhibit, and our day's host, Dr. Michael M. Shara will deliver the following two lectures:

Einstein's Revolution—He was daring, wildly ingenious, passionately curious. He saw a beam of light and imagined riding it; he looked up at the sky and envisioned that space-time was curved. Albert Einstein reinterpreted the inner workings of nature, the very essence of light, time, energy, and gravity. His insights fundamentally changed the way we look at the universe.

10 Discoveries from the Hubble Space Telescope—In the 20 years it has been in orbit, Hubble has revolutionized our understanding of how the universe works. Images from the telescope have become iconic forms of modern art. And lurking in each image is new science. Dr. Shara will describe 10 remarkable discoveries made with the Hubble, and show how its images reveal something we've never seen or understood before.

VIRTUAL WORLDS

Speaker: **Jeremy Bailenson, Ph.D.**

- Buying and Selling 1's and 0's: How Virtual Reality Changes Marketing
- Virtual Bodies and the Human Identity: The Proteus Effect
- Transformed Social Interaction in Virtual Worlds

BRAIN DIMENSIONS

Speaker: **Nancy C. Andreasen M.D., Ph.D.**

- The Brain's Odyssey through Life: Development and Aging Across the Lifespan
- The Creative Brain: The Neuroscience of Genius
- Venus vs. Mars or the Age of Androgyny? Gender and the Brain

RATIONAL THOUGHT — AND NOT

Speaker: **Michael Shermer, Ph.D.**

- The Bermuda Triangle and Other Weird Things that People Believe
- Why Darwin Matters: Evolution, Intelligent Design, and the Battle for Science and Religion
- The Mind of the Market: Compassionate Apes, Competitive Humans, and Other Lessons from Evolutionary Economics

UNIVERSAL QUESTIONS

Speaker: **Max Tegmark, Ph.D.**

- The Mysterious Universe
- The Inflating Universe
- The Mathematical Universe

ARCHAEOLOGY/ANTHROPOLOGY

Speaker: **Jerald T. Milanich, Ph.D.**

- Belle Glade Cultures — Secrets from 500 BC to AD 1700
- Documenting Florida's Seminoles — Adventure Behind the Scenes
- Archaeology of the Spanish Colonial Southeast U.S. After 1492

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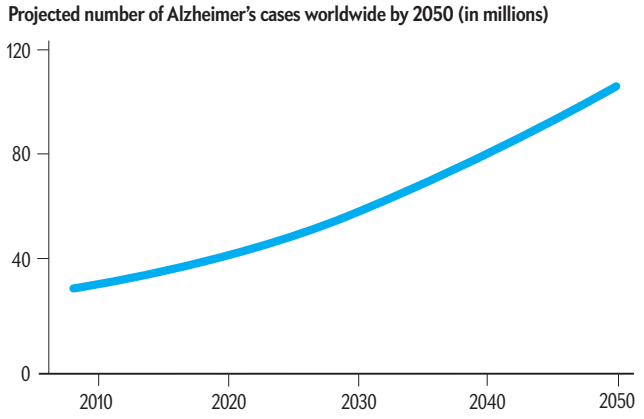
Memory hole: **Researchers at Johns Hopkins estimate that by 2050 more than 106 million people worldwide will have Alzheimer's disease if effective treatments are not found.**



make dementia worse does not mean that preventing them will delay the brain's overall deterioration. Maybe severe dementia makes people more vulnerable to microinfarcts. And just because better control of high blood pressure and increased physical activity seem to decrease a person's risk of stroke, that does not necessarily mean they are less likely to suffer microinfarcts. Correlation, after all, does not necessarily imply causation. That scientific truism was the problem that kept bothering the panel of outside experts put together by the NIH. Thus, the expert panel concluded, with one exception, that "all existing evidence suggests that antihypertensive treatment results in no cognitive benefit." Data showing the benefits of boosting physical activity in folks with confirmed memory problems were "preliminary."

The controversy boils down to semantics, says Martha L. Daviglus, chair of the consensus panel and a preventive cardiology researcher at Northwestern University's School of Medicine. "Obviously, smoking and hypertension are risk factors for cardiovascular disease," she says. "And they may turn out to be risk factors for Alzheimer's disease as well," she says. But after reviewing all the evidence, Daviglus and her fellow panelists concluded that it "failed to provide convincing evidence" of the link, whereas other researchers see "some evidence" of a link.

Getting better data may be a problem, however. One of the best ways scientists have to prove cause and effect in medicine is to conduct a randomized controlled trial, in which study subjects are randomly assigned to two groups. One group—the so-called control group—receives the usual standard of care. The other group—the so-called experimental group—gets whichever intervention is being tested. The simplest way to prove that treating high blood pressure helps to delay the onset of dementia would be to treat one group for hypertension and leave the other group deliberately untreated for the sake of the experiment. No ethical physician would participate in such a study.

One way out of this dilemma, Daviglus notes, is to design a study in which patients suffering from hypertension get treatment, and doctors analyze the results based on how well the patients' blood pressure was controlled. If the amount by which blood pressure dropped closely paralleled the decrease in dementia risk, that would be powerful evidence of a beneficial link. Such a so-called dose-response study has not been done yet—it is a complex and expensive undertaking—but there is reason to believe it could be worth the investment.

Observational studies, which follow people as they get older without directly intervening in their treatment, have uncovered some suggestive trends. Larson and others have shown that people who have good control of their blood pressure from age 65 to 80 are less likely to develop dementia. After age 85, controlling blood pressure does not have much effect on dementia risk. That doesn't mean anyone older than 85 should stop taking blood pressure medication. Lowering high blood pressure still prevents congestive heart failure and promotes kidney health. But these studies suggest that doctors do not have to take aggressive measures when treating patients older than 85 for hypertension.

As for physical activity, the best evidence in favor of its benefits for the brain comes from Australia. Two years ago researchers there published the results of a randomized controlled trial of physical activity in 170 older adults who had started showing greater memory problems than their peers and were thus at increased risk of developing dementia. Study participants averaged an extra 20 minutes a day of physical activity over six months. The study was so rigorously designed that individuals undertook the extra exercise by themselves at home to preclude the possibility that the true benefit had come from socializing with other people during group activities. The benefits of extra exercise were obvious and lasted—albeit at a diminishing level—for 12 months after the exercise program ended. Not only did the experimental group score better on tests of their cognition compared with the control group, but the improvement was twice as great as the one that had previously been shown for the antidementia drug donepezil (brand name Aricept). This was the first time that anyone had proved in a randomized controlled trial that exercise could improve mental functioning in people with some cognitive problems.

No one understands on a biochemical level why physical activity might help the brain. The best explanation so far, says Henrietta van Praag, a neurobiologist at the National Institute on Aging, is that exercising the heart somehow stimulates growth factors to produce new nerve cells in the brain. In 1999 van Praag showed that more new nerves formed in the hippocampus—one of the key centers in the brain for memory and learning—in physically active mice than in inactive ones. (She was working at the time as a postdoctoral researcher in Fred Gage's laboratory at the Salk Institute.) She has since shown that the new cell growth is associated with a marked improvement in learning and memory. The new nerves also show qualitative differences from their older counterparts. The younger cells are better at establishing new connections with other cells. The effect is somewhat temporary. After a couple of months, the new cells start acting like the older cells, although they do not die off.

Maybe 10 or 15 years in the future, we will know for sure whether quitting smoking and exercising regularly help to delay dementia. That leaves the rest of us—who may have seen the devastating effects of dementia on older family and friends and cannot afford to wait for a definitive scientific answer on how we might avoid a similar fate—in an uncomfortable state of ignorance. Even if these steps never end up helping your brain, however, they will do your heart a world of good. SA

FOR MORE ON ALZHEIMER'S www.ScientificAmerican.com/dec2010/alzheimers

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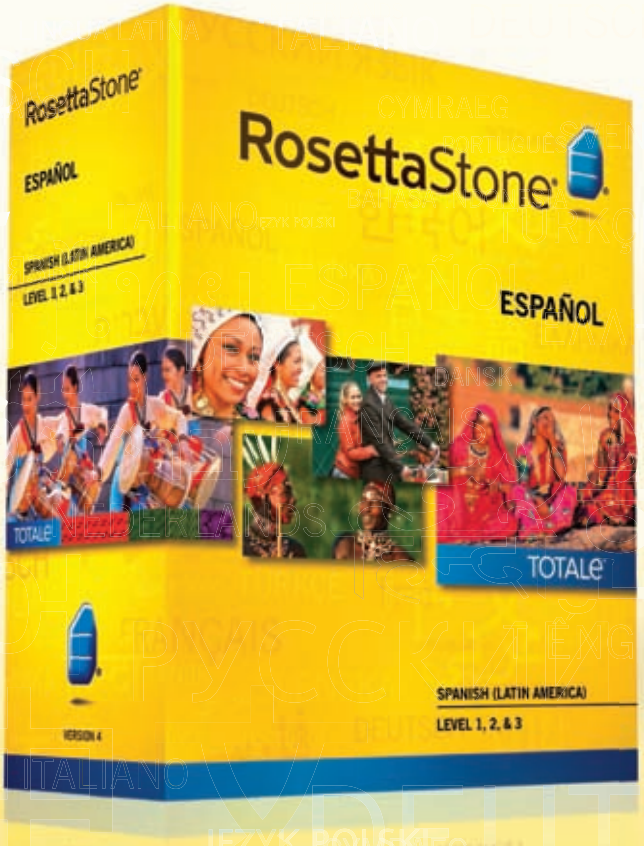

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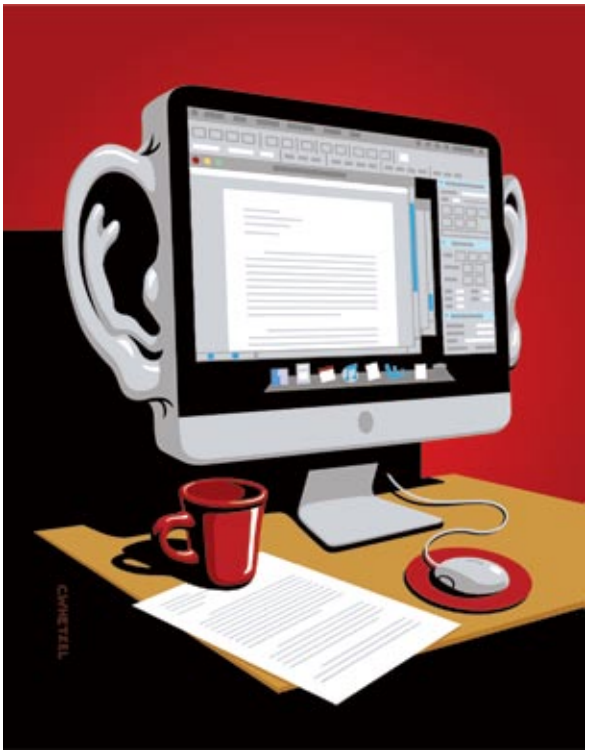
David Pogue is the personal-technology columnist for the *New York Times* and an Emmy Award–winning correspondent for *CBS News*.

Talk to the Machine

Speech-recognition programs are no longer clumsy exercises in futility

In the past couple of years speech-recognition software has quietly grown tendrils into every corner of our lives. It's at the other end of customer-support hotlines and airline reservation systems. It's built into Microsoft Windows. It's an alternative text-input method for touch-screen phones such as the iPhone and the Android. But let's face it: most people who use this software wish they didn't have to.

That's because speech recognition is usually plan B: a least terrible alternative to typing or actual human conversation. Corporations use it for their phone systems because it's cheaper than hiring real people. Many people who dictate into their computers do it because they must, perhaps because of a disability. And speech recognition is cropping up on touch-screen phones because typing on an on-screen keyboard is slow and fussy.



So what would it take to make speech recognition more than a work-around? How close are we to the *Star Trek* ideal of conversational computers that never get it wrong?

Well, we're getting there. It turns out that after a decade of buyouts, mergers and embezzlement scandals, there is only one major speech-recognition company left: Nuance Communications. It sells the only commercial dictation software for Windows, for Macintosh and for iPhone. Its technology drives the voice-command systems in cars from Audi, BMW, Ford and Mercedes and cell phones from Motorola, Nokia, Samsung, Verizon and T-Mobile. It powers voice-activated toys, GPS units and cash machines, and it answers the phone at AT&T, Bank of America, CVS and many others.

Every year Nuance releases another new version of its consumer dictation programs, such as Dragon NaturallySpeaking. Usually it doesn't add many new features. Instead it devotes most of its resources to a single goal: improving accuracy.

In the beginning, you had to train these programs by reading a 45-minute script into your microphone so that the program could learn your voice. As the technology improved over the years, that training session fell to 20 minutes, to 10, to five—and now you don't have to train the software at all. You just start dictating, and you get (by my testing) 99.9 percent accuracy. That's still one word wrong every couple of pages, but it's impressive.

Speech engineers use all kinds of tricks to boost accuracy. The earliest dictation programs required you to pause after each word; the software had no clue how to distinguish "their" from "there" and "they're." But in time, ever more powerful PC processors made continuous-speech analysis possible. Today you are encouraged to speak in longer phrases, so the software has more context to analyze for accuracy.

Another trick: Last year Nuance offered a free dictation app for the iPhone, called Dragon Dictation. What you say is transmitted to the company's servers, where it is analyzed, converted to text and zapped back to your screen within seconds.

What nobody knew, though, is that the company *stored* all those millions of speech samples, in effect creating an immense storehouse of different voices, ages, inflections and accents against which to test different recognition algorithms.

So, yes, the technology is improving. But readers often ask me: "If dictation software is so good, can I use it to transcribe phone calls and interviews?"

The answer is still no. The software isn't much good unless you are speaking into a microphone, without background noise, preferably without an accent. You still have to speak all punctuation ("comma"), like this ("period"). And goodness knows, we humans have enough trouble understanding each other; it's a bit much to ask for a computer to get it all right. No wonder today's dictation apps still make mistakes such as "mode import" for "modem port," "move eclipse" for "movie clips," and "oak wrap" for—well, you get it.

So, no, the keyboard isn't going away in our lifetime. Conversational-style *Star Trek* computing is still decades away. Sure, 99.9 percent accuracy is darned good—but until it reaches 100, speech-recognition technology is still plan B. SA

FOUR VOICE-RECOGNITION TIPS www.ScientificAmerican.com/dec2010/pogue

Illustration by Chris Whetzel

Germany Inspires Innovation — Welcome to Europe's Leader in Science

AN INITIATIVE OF THE

Federal Ministry
of Education
and Research

Research in Germany

Land of Ideas

www.research-in-germany.de

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Germany can draw on a rich scientific and cultural heritage: It is a land where tradition and innovation go hand in hand.

Welcome to the Land of Ideas

Excellence in research and development

Germany is the number one location for research in Europe. Germany's unique scientific tradition and great variety of research offer ideal conditions—not only for people with ideas, but also for companies that want to translate these ideas into new products. German inventions and discoveries—such as the car, theory of relativity and MP3 format—have changed the world. Research-intensive products and services contribute 45% to value creation in Germany, more than in any other industrialized country.

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Spreading the seeds of ideas.

"Made in Germany" is a seal of quality

One of Germany's major strengths is translating research findings and development into specific products. Traditionally, such efforts are made in such sectors as electrical engineering and car manufacturing as well as in mechanical and systems engineering. "Made in Germany" is recognized across the world as a seal of quality for sophisticated technology and excellent workmanship. With 396 internationally relevant patents per million inhabitants, Germany far exceeded the European average of 158 in 2007.

Moreover, for more than 20 years, Germany has led Europe in research-intensive key technologies. More biotech companies have been established in Germany than anywhere else in Europe. Additionally, German nanotechnology firms account for roughly half the number of European companies active in this field. Germany sees itself as the "Gateway to Europe." As an export-oriented country, Germany can build on many years of experience in the field of international cooperation.

Looking forward to the future

The German Federal Government recently started several groundbreaking initiatives to further strengthen Germany's level of excellence. With the *High-Tech Strategy* and *Pact for Research and Innovation*, the Federal Government is investing more in research and development than ever before, with a strong focus on partnerships with the industry and international collaborations in key future sectors. The Initiative for Excellence is turning Germany's best universities into top research universities, thereby sponsoring the best brains in the country and attracting talented students and top foreign researchers from all around the world.

Germany—a leading nation in research funding

The German Federal Government provided funding of roughly 12 billion Euros for research and development in 2009. German companies invested approximately 46 billion Euros in this field. Germany thus takes fourth place internationally, following the U.S.A., Japan, and China. Research expenditure accounts for 2.64% of GDP—the highest percentage since German unification.

Excellence with passion:
In German laboratories top international researchers work closely together combining their various types of expertise.

Research in Germany — Diversity and team work

Creative ideas bear fruit when they are encouraged and promoted in various ways. This also gives unconventional solutions a chance. The exceptional diversity of the German research system is the result of Germany's federal structure and outstanding scientific traditions developed over the centuries. The unique system rests essentially on three pillars: public-sector research including universities and universities of applied sciences (Fachhochschulen), private-sector research in companies and research in non-university research institutions.

Four big names for cutting-edge science

The third pillar includes the four major German research organizations. They are named after Hermann von Helmholtz, Max Planck, Joseph von Fraunhofer and Gottfried Wilhelm Leibniz — four German scholars pivotal in shaping modern science and technology.

Research activities at the 16 centers of the **Helmholtz Association**, which are active in the fields of science and technology, as well as medicine and biology, mainly involve large-scale, cutting-edge scientific research facilities. This excellent infrastructure is available to national and international research groups. The **Max Planck Society** focuses on basic research. Its 80 institutes are internationally renowned for their quality research in the fields of physics, chemistry, biology, medicine, social sciences and the humanities. The emphasis of the **Fraunhofer-Gesellschaft** is on application-oriented research that places its 60 institutions at the forefront of innovation. All of them are involved in contract research for industry, the service sector and public authorities. The **Leibniz Association** combines 86 highly specialized independent institutes whose focus is linking scientific excellence with research-based advice for industry, society and politics.

Cooperation is a matter of course

Beside these four organizations, there are more than 450 foundations and ten scientific academies providing support for research in Germany. The **Deutsche Forschungsgemeinschaft (DFG)** is the central, self-governing research-funding organization in Germany. Its mission is to fund and promote all fields of science and the humanities. The **German National Academy of Sciences Leopoldina** has represented German researchers on international bodies since 2008. In cooperation with the **German Academy of Science and Engineering (acatech)** and the science academies of the German states (Länder), it provides policy-makers and the general public with science-based advice on technology-related issues and promotes dialog between science, industry, politics and society. Federal and state institutes conduct research in fields that involve government tasks in the areas of nutrition, agriculture risk-prevention and more. This diverse research environment makes it a matter of course for German researchers to engage in research collaboration.

"It is a great honor for me to receive the Alexander von Humboldt prize. With this prize budget we have a lot of new opportunities to make ourselves even stronger and to become one of the key players in this field worldwide. For me personally that is an interesting opportunity to set up an internationally renowned working group."

Prof. Dr. Gerard J. van den Berg, Netherlands, is an Alexander von Humboldt Professor in Econometrics and Empirical Economics at the University of Mannheim. His primary research interests are in health and labor economics.

www.helmholtz.de
www.mpg.de
www.fraunhofer.de
www.leibniz-gemeinschaft.de
www.acatech.de
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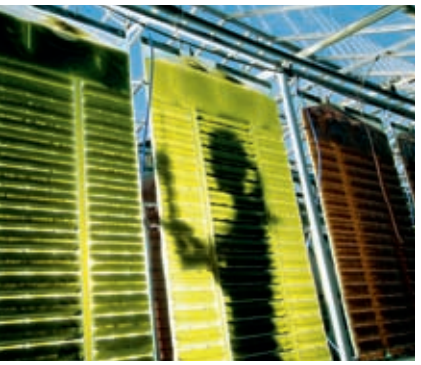
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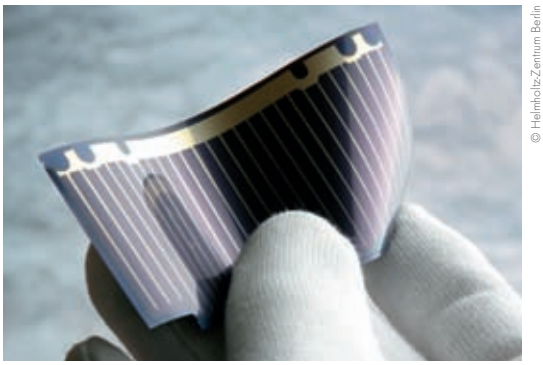
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The High-Tech Strategy for Germany — A successful model for Europe

Climate-protection and energy. Mobility and security. Health and communication. The challenges facing the global community can only be mastered if enormous progress is made in research and innovation. With its *High-Tech Strategy*, the German Federal Government provides a framework that involves all political players and focuses the national strengths in science, technology and industry on those issues vital for our future. The aim is to open new leading markets and encourage further cooperation between science and industry through networks and clusters. As a result, excellent research results can be translated even more quickly into new technologies, products and services.

The High-Tech Strategy is a success story: German companies increased their investments in research and development 19% between 2005 and 2008. The number of industry researchers, lab assistants and technicians employed in 2008 rose by 12% compared with 2004. Moreover, the High-Tech Strategy also extends beyond Germany. The European Commission recently initiated a similar process with its "Europe 2020" strategy. Excellent universities, research centers and companies in European partner countries are networking their activities on important forward-looking topics under the umbrella of the European Institute of Innovation and Technology (EIT) and Joint Technology Initiatives (JTI).

Small- and medium-sized companies — Drivers of German innovation

Innovation in Germany is strongly driven by small- and medium-sized enterprises (SMEs) that translate results of academic research into marketable technologies. Consequently, a crucial instrument within the High-Tech Strategy is the SME funding initiative, "KMU-innovativ." Since 2007, with this program, the German Federal Ministry of Education and Research has helped companies shoulder risks related to cutting-edge research. So far, approximately 450 projects with a financial volume of 300 million Euros have been funded, covering such areas as biotechnology, technologies for energy and resource-efficiency, information and communication technologies, nanotechnology, optical technologies, production technology, security technologies and microsystems.

Leading-Edge Clusters — A strong interface with the industry

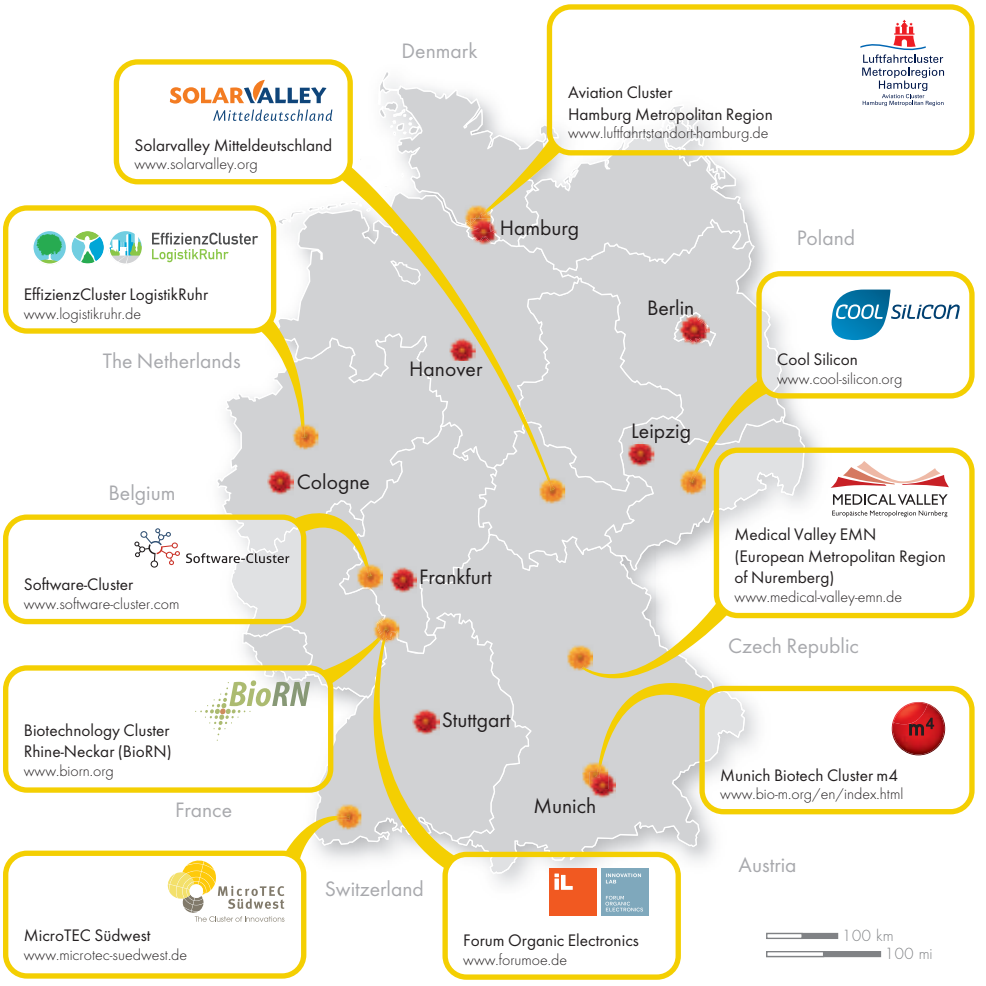
The Leading-Edge Cluster Competition is another central instrument within the High-Tech Strategy of the German Federal Government. It promotes innovative clusters that bring together all stakeholders throughout the value chain — from idea to product to user — on a long-term basis. This will generate synergies and accelerate the commercialization of new products, processes and services. Ten Leading-Edge Clusters have already been selected in two rounds of the competition. Each cluster receives funding of 40 million Euros for five years, among them the

SMEs are highly creative

Funding of roughly 300,000 Euros helped the Bavarian biotech company Pharmazell GmbH to produce bile acids using genetically modified bacteria. These acids, which help to treat not only gallstones but also cirrhosis and other diseases of the liver, were previously produced by means of complex chemical processes. The biotech company Matricel received roughly 500,000 Euros for the production of specific base material for regenerative medicine made from high-purity porcine collagen that can be used as guide structures for the regeneration of nerve fibers.

www.hightech-strategie.de
www.spitzencluster-wettbewerb.de
www.kmu-innovativ.de

Germany's Leading-Edge Clusters



Biotech Cluster in the Munich region, Solarvalley Mitteldeutschland, or the Cool Silicon Cluster in Saxony. The third round of the Leading-Edge Cluster Competition is planned for late 2010.

Translating good ideas into practice — Highlights from the High-Tech Strategy

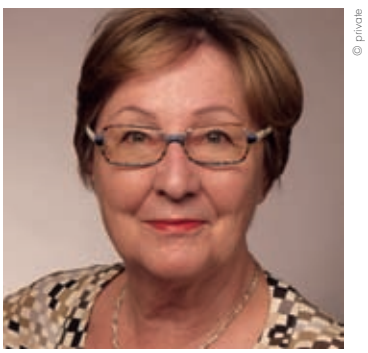
Energy — 25,000 hours of continuous operation set a new world record for high-temperature fuel cells. It was established at the Research Center Jülich of the Helmholtz Association in June 2010. With their broad expertise in materials research, computer simulation and engineering sciences, the researchers in Jülich are making a decisive contribution in the development of diverse types of fuel cells that provide an efficient and practical alternative for stationary and mobile electricity generation.

Climate — The new Institute for Advanced Sustainability Studies (IASS) in Potsdam (near Berlin) is devoting itself to the great processes associated with climate change. The institute is an attractive place to work for visiting scientists from all over the world, thanks to the international reputation of the Institute's founding director Prof. Dr. Klaus Töpfer, former Executive Director of the United Nations Environment Program, as well as its partnership with the renowned Potsdam Institute for Climate Impact Research (PIK) and the German Research Center for Geosciences (GFZ).

Mobility — The future of the automobile belongs to hybrid and electrically powered vehicles. Not surprisingly, the German motor vehicle industry is highly active in this field. Daimler AG,

With the High-Tech Strategy the German Federal Government has formulated clear objectives and concrete action plans to foster innovation in five fields of action: Climate/Energy, Health/Nutrition, Mobility, Security, and Communication.

Biomass is an important renewable energy source of the future. The High-Tech Strategy is leading the way in this field: German scientists developed a reactor platform for the production of algae biomass from CO_2.



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"Close and efficient cooperation between science and industry is the best way to ensure that our High-Tech Strategy is successful. We are working together to transform today's visions into tomorrow's reality — for example through the Leading-Edge Clusters."

Anne-Kathrin Deutrich
is Chair of the Executive Board of Testo AG, which is a member of MicroTEC Southwest — one of the winners of the Leading-Edge Cluster Competition funded by the German Federal Ministry of Education and Research. She is also a Member of the University Council of the University of Freiburg.

The Alfred Wegener Institute for Polar and Marine Research is leading in climate research. Balloon-based measurements of atmospheric parameters over the Arctic help with the construction of climate models.

Germany is the number one location for automobile technology. In recent years it also has become a pioneer in all fields of sustainable mobility, such as the engineering of clean, electrically powered cars.

for example, is cooperating with Evonik Industries AG in East Germany to develop a technology for the production of lithium-ion batteries. The "Innovation Alliance Lithium-Ion Batteries" is focusing on the next-generation-but-one of storage batteries. Scientists from various Fraunhofer institutes in Germany and the United States are cooperating closely with their US colleagues within the framework of the "Alternative Energy Technologies for Transportation" program.

Security—The failed attempt to blow up a plane over Detroit on Christmas Day in 2009 has sparked new calls to reinforce airport security. However, highly secure, state-of-the art full-body scanners have caused public outrage because they virtually undress people. Researchers from the Institute of Photonic Technology in Jena are developing a camera that performs the screening passively by tracing the shadows of suspicious objects on a person's terahertz radiation, which the human body emits naturally in the form of heat. This eliminates the exposure to radiation and the naked appearance of the recorded images. The "THz-Videocam" is one of over 70 projects currently funded under the "Research for Civil Security" program of the German Federal Government that aim to develop innovative technologies to protect people in our modern, complex societies against terrorism, organized crime, natural disasters or large-scale accidents.

Health Research—Personalized medicine will be standard practice one day, but it requires efficient translation of knowledge from bench to the bedside. The German Federal Government will therefore establish new research structures in this area so patients can benefit more quickly from the results of research. For example, partners from research institutes, universities and university hospitals at the six "German Centers for Health Research" focus on the major common diseases of diabetes and neurodegenerative diseases as well as infections, cancer, heart and lung diseases. These will be National Centers of Translational Research that draw on various disciplines and foster interdisciplinary cooperation. Systems biology produces decisive progress in this area: Medical and pharmaceutical researchers are working together with experts in the fields of molecular biology, mathematics, computer science and engineering. Seventy groups from 41 institutes are cooperating in Germany's unique "Virtual Liver Network" in order to develop the first computer model of a complete human organ. This will enhance our understanding of the origin of diseases and the effects of drugs and make it possible to develop customized drugs more quickly and more economically.

Information and Communication Technology—The Max Planck Center for Visual Computing and Communication links two of the world's leading institutes: the Max Planck

"Real applications like LiSA show the potential of service robotics for real tasks. They bring the new market for service robotics closer!"

Dr. Roko Tschakarow
Head of Business Unit/Head of Sales, Mechatronic Components and Solutions, SCHUNK GmbH & Co. KG in Lauffen/Neckar, which participated in the development of LiSA.

German companies are at the forefront of developing technologies for renewable energy production. This Solar Mover made by the Solon Company in Berlin is just one out of many exciting innovations in this field.

Institute for Computer Science in Saarbrücken and Stanford University. The Center serves primarily to support particularly well-qualified young scientists in a key area of computer science. It enables post-doctoral researchers to conduct independent research with a small working group under the supervision of a mentor from Germany and a mentor from the United States for up to five years, initially in the United States and subsequently in Germany.

Key technologies "Made in Germany"

Production Engineering—LiSA is operational 24 hours a day, reliable, easy to operate and doesn't shrink from work involving hazardous substances. These are the best qualities for assisting researchers life-science company laboratories. LiSA is a mobile robot that can take over limited tasks independently and move around to individual experimental stations. It was developed by a joint research project headed by the Fraunhofer Institute for Factory Operation and Automation. LiSA shows that solutions from robotics can be considerably more flexible and economical than classical automated solutions.

Nanotechnology—Nano particles can serve as helpers in the field of medicine. For example, Magnetic Particle Imaging (MPI) technology is a fundamentally new method of medical imaging invented by Philips Research in Hamburg that measures the concentration of ferrous oxide nanoparticles previously injected into the body. MPI can depict processes in real time in either heart or blood vessels.

Innovative Services—In the near future, even people who require care and assistance will have the opportunity to grow old in their own homes. Industry research partners from Fraunhofer-IMS in Duisburg have developed SAMDY (Sensor-based Adaptive Monitoring System) to support nursing staff in their demanding work. Wireless sensors provide a home station that relays 24/7 data about potentially hazardous situations regarding the health of old or sick individuals. The information is processed for the nursing staff and fed directly into the documentation and billing system. Staff can therefore devote more time to the patient.

Biotechnology—"Biomass instead of oil." This is the motto for the green chemical factory of the future. But transferring biotechnological processes from the laboratory to industrial applications is often more difficult than one might imagine. The Chemical-Biological Process Center (slated for Leuna, a chemical site with a long-standing tradition), is intended to solve this problem. Beginning in 2011, research institutes as well as companies will be able to test and develop their biotechnological processes at this pilot plant; the only one of its kind in Europe.

"I like being motivated by real-world problems. At Fraunhofer I have the opportunity to pursue a highly pragmatic approach to challenging research questions close to industrial applications. My colleagues and I do not just want to solve problems, we are also keenly interested in the benefit the solutions will yield."

Dr. Kristian Kersting who started his research career in Germany and the USA (MIT) is currently being funded by the Attract program, which gives outstanding scientists the chance to set up their own working groups at a Fraunhofer Institute.

Minister Annette Schavan welcomes young international scholars on the roof terrace of the Reichstag building, seat of the German parliament.

The German research system is highly efficient and internationally competitive

Interview with Annette Schavan, Federal Minister of Education and Research

Your research funding is considered ground-breaking. How do you view the situation to date?

Extremely positively! Our High-Tech Strategy is setting the course in the high-demand areas of health, climate and resource protection, mobility and security. We have successfully established innovation alliances between science and industry, thereby focusing on networking, clusters and small- and medium-sized enterprises. The Pact for Research and Innovation has strengthened non-university research institutions; and our Initiative for Excellence has once again positioned our universities at the center of the German science system.

What are the thematic strengths of research in Germany?

Germany is European leader in the field of environmental technology, thanks to a legal framework and government research funding that encourage innovation. We are pioneers in research into renewable-energy use. Our health research is on the way to ensuring the strategic networking of research institutions, universities and teaching hospitals. Medical technology is the backbone of the German health industry. Germany holds a leading position in the key technologies. For example, German companies are among the world leaders in optical technologies. In the field of biotechnology, Germany is the leading location in Europe.

How can the state and industry cooperate even better to ensure research excellence?

We are increasing government funding for R&D. This, in turn, will trigger more R&D investments on the part of industry. Cooperation between industry and science also plays a central role in the Pact for Research and Innovation. The Initiative for Excellence serves to intensify cooperation with industry through measures that encourage the transfer of technology. More than half of the graduate schools are involved in cooperation projects with business partners, such as internship or scholarship programs.

What are the markers for success?

In recent years, we have been delighted to see four German scientists win the Nobel Prize: 2005: Theodor W. Hänsch/Physics (2005); Gerhard Ertl/Chemistry (2007) and Peter Grünberg/Physics (2007); Harald zur Hausen/Medicine (2008). Germany can also be proud of its patents

record. Research institutions concluded 679 IPR agreements in 2009. This means we are first in Europe, and third worldwide behind only the United States and Japan.

What is the international response to the Initiative for Excellence and the Pact for Research and Innovation?

Thirty-seven universities are currently receiving funding under the Initiative for Excellence. The aim is for them to establish themselves as leading international institutions performing cutting-edge research. Thanks to the Initiative for Excellence, we have increased the attractiveness of German universities for students and scientists from both home and abroad. Roughly 4,200 researchers have been recruited under the funded projects so far, with approximately 25% of them from abroad. Approximately 85% of the reviewers involved are from other European countries or North America, with most of the professors and post-docs recruited by the clusters of excellence and graduate schools from the United States. India and China take the lead with regard to the number of doctoral students. The Alexander von Humboldt professorships are a further instrument for attracting top researchers from abroad.

"We all benefit when young, international scholars research together. Welcome to the Land of Ideas."

What are the priority areas for research cooperation with the United States and Canada?

The United States is one of our most important partner countries. German and American scientists cultivate a lively exchange – on almost all relevant topics and at all career levels. There are currently over 1,400 cooperation projects. More than 50 cooperation agreements between individual institutions form the basis for a close network. Priority areas are space activities, environmental technology, as well as climate and environmental research. This close cooperation is also evident in the joint use of large research facilities in the United States and Europe. In the future, we will also cooperate more closely on the major issues of the 21st century, climate and energy research, as well as in various areas of health research. Our relationship with Canada is also characterized by a long history of joint research projects.

"Investments in research and innovation take priority — precisely in times of economic crisis. We will invest a further 12 billion Euros in education and research over the next four years."

How do you rate the development of the European Research Area?

The key aims of the European Research Area are the improved use of scientific resources, increased competitiveness, better coordination of research activities at national and European levels, the development of human resources, as well as steps to attract the best researchers worldwide. Germany plays a leading role in the process of European unification, and we are integrating international research partners in European projects. Russia and Israel are prominent examples. Germany has been Israel's most frequent partner in cooperation projects in both the 6th and 7th Research Framework Program. Germany is actively involved in strategic networking with Russia, among other things through its coordination of research policy dialog involving a wide range of stakeholders.

What are the next priorities in your policy?

We will continue to link science and industry and to pool strengths. This is the only way to translate ideas into successful products. We will introduce and encourage new forms of cooperation, launch new innovation alliances for the markets of tomorrow and continue to expand clusters and networks, involving small- and medium-sized enterprises. Our universities and research organizations should attract young researchers and give them the space to develop their scientific talents and creativity in Germany – the "Land of Ideas." At the international level, we will continue to expand our cooperation with developing and emerging countries. Research for sustainable development will play an increasingly important role in this context.

Germany offers perfect conditions to do research. This also means that research institutions and universities make it possible to reconcile family and career.

Germany — An excellent location for research and teaching

"Whenever I talk about the Initiative for Excellence in the United States, I meet with tremendous interest in this competition and hear great praise for it. Cutting-edge research in Germany has thus become much more visible internationally."

Prof. Dr. Ing. Matthias Kleiner
President of the Deutsche Forschungsgemeinschaft

Initiative for Excellence:
www.dfg.de/foerderung/programme/exzellenzinitiative
www.wissenschaftsrat.de/arbeitsbereiche-arbeitsprogramm/exzellenzinitiative/

Funding opportunities:
www.kisswin.org
www.daad.de
www.humboldt-foundation.de
www.dfg.de

Job and family:
www.research-in-germany.de/faq

German universities lay the foundations for outstanding scientific careers and achievements. Twelve out of every 100 graduates go on to take a doctorate — this is world's highest ratio. Another criterion for measuring the reputation of a research nation is the number of scientific publications per million inhabitants. In Germany, this number increased by 20% to 1,046 between 2000 and 2008. This is more than Japan (623) and only slightly less than the U.S.A. (1,077).

Consequently, universities and renowned non-university research institutions (such as the Max Planck Society and the Helmholtz Institutes) attract talented researchers from all over the world. Currently, more than 26,000 international scientists are working in Germany. Among them are some of the world's most-cited researchers, such as Professor Simon White, Director at the Max Planck Institute for Astrophysics in Munich, and Professor Iain Mattaj, Director General of the European Molecular Biology Laboratory (EMBL) in Heidelberg.

Outstanding conditions for a career in Germany

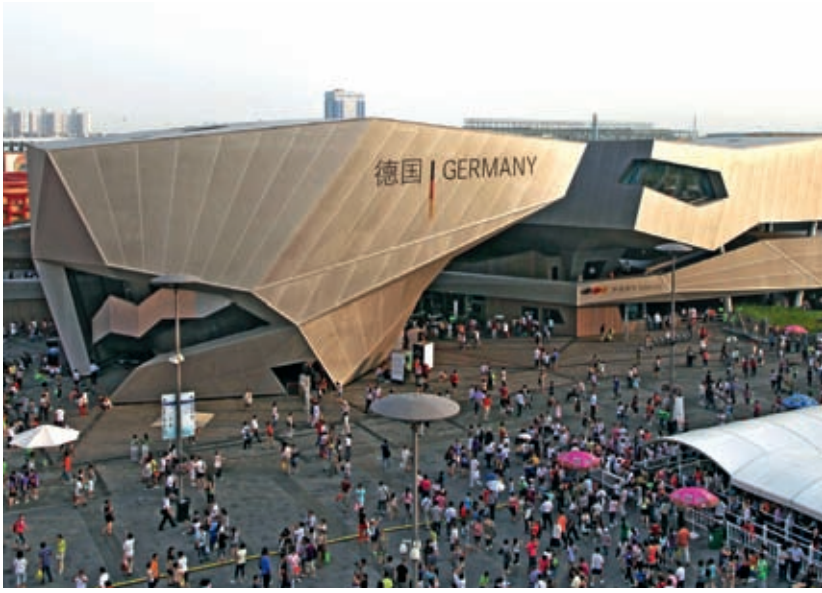
Thanks to the Initiative for Excellence, German universities are becoming even more visible internationally — and more competitive. So far, 1.9 billion Euros have been granted to 85 institutes at 37 universities. Funding has been provided to outstanding areas in all disciplines, ranging from the Graduate School of Computational Engineering in Darmstadt to the "Oceans of the Future" research project in Kiel. Non-university research is receiving large grants within the framework of the Pact for Research and Innovation. The dynamism of the German research landscape has already won the approval of high-caliber scientists from the United States.

Marc Levine has opted for a career in Germany. The renowned mathematician from Northeastern University in Boston, Massachusetts, moved to Essen in 2009 to set up a working group on algebraic geometry. Levine will hold a generously endowed Alexander von Humboldt professorship, one of the instruments with which Germany is attracting top scientists. The successful applicants receive up to 5 million Euros provided by the Alexander von Humboldt Foundation for five years.

Child or career? In Germany you can have both

German research institutions and universities help women and men reconcile family and a science career. For example, the Helmholtz Association already has its own nursery facilities in all of its institutes. The Max Planck Society is also steadily expanding its facilities in order to help its staff with child-care matters.

Germany — A strong player in the global scientific community



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German scientists and entrepreneurs present their cutting-edge research at conferences and trade fairs worldwide, for example at the Expo 2010 in Shanghai in the impressive German Pavilion.

Germany is open to new ideas. German science seeks contact with the best scholars worldwide and welcomes young, talented researchers. Numerous public and private funding programs ensure a lively exchange of knowledge. Every year, the German Academic Exchange Service (DAAD), with branch offices in San Francisco and New York, supports 21,000 Germans during their stays at research institutions abroad, while also helping 36,000 foreigners to come to Germany. The Heisenberg and Emmy Noether Programs enable young researchers to work independently in Germany for a period of several years. The Leibniz Association, Max Planck Society and Fraunhofer-Gesellschaft send doctoral students abroad and welcome guests from all over the world. The states (Länder) have also established numerous cooperation programs in the scientific field.

Germany is the gateway to European research

Between 2007 and 2013, the European Union is providing funding of 54.4 billion Euros for innovative projects under the 7th Research Framework Program (FP7). Germany is contributing almost 20% of the funds, with German researchers involved in more than 70% of the projects. Non-European countries are also involved in the projects. First and foremost, the United States. For scientists from the United States, access to Europe is often via Germany; evidenced by the EU-funded large-scale project "Sybilla." In this program, the Max Planck Institute for Immune Biology, the German Cancer Research Center and Magdeburg University are cooperating with two institutes at Harvard Medical School and 12 other European partners to develop new approaches to treating auto-immune diseases.

German universities are present all over the world

Over the last ten years, German universities have established more than 60 study courses worldwide — supported among other things by the DAAD. There is a particularly high demand for German training in the field of engineering as well as in economics and the natural sciences. The German University Cairo and the German-Jordanian University have met with keen interest in the Middle East, while the German-Turkish University in Istanbul is currently being established. The German universities are actively courting the brightest brains. To this end, they launched the GATE Germany initiative that seeks contacts with scientists in countries such as China, South Korea, Brazil and India. In addition, German researchers present their cutting-edge work at trade fairs and events worldwide, including the fields of nano- and environmental technologies.

www.study-in.de
www.research-in-germany.de
www.euraxess.de
(Exchange opportunities for researchers)

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Well-trained skilled workers are of key importance for a high-tech location like Germany.

Quality training "Made in Germany"

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"We are impressed that the German government supports the internationalization of German training providers by establishing the initiative iMOVE. As a neutral and independent government body, iMOVE promotes international cooperation and facilitates business relations among companies and organizations in the field of vocational and technical training. We recommend using iMOVE services. Working with a German partner has opened up new and exciting business opportunities for us".

Dr. Steve Lai
Chief Executive Officer (CEO), PSB Academy Pte. Ltd., (A member of TÜV SÜD Group), Singapore

www.bmbf.de/en
www.bibb.de/en
www.imove-germany.de

In Germany, not only academia generates top professionals. Germany's unique vocational education and training system is very highly regarded internationally and produces excellent specialists — from the assistant in the live sciences lab to the IT systems engineer. Under the so-called Dual System, young people continue to attend school part-time alongside their practical training in a workshop or company. At these vocational schools, they not only gain a specialist's theoretical knowledge but also communicative and social skills. This gives young employees more comprehensive training and better chances in the labor market. Furthermore, the standardized final qualifications for the Dual System's approximately 350 training occupations mean their performances are comparable. On the other hand, by providing two to three years of in-company training, employers can ensure the availability of the next generation of highly qualified staff — without the need for extensive recruitment procedures.

Lifelong learning in a changing world

It is essential to continue learning and developing professional skills — especially in times of a rapidly changing working world. The German Federal Government supports this lifelong learning with "continuing education vouchers" for employees with low or medium incomes. The "Local Learning" program is bringing the various education providers together at the local level in 40 selected model towns. The Federal Government's activities are supported by 120 foundations in a unique public-private partnership. Local education-management agencies develop clear, coordinated modules from the wide range of courses offered, thus facilitating access to continuing vocational training.

German-quality training is available worldwide

Companies and organizations worldwide can also profit from Germany's formidable vocational training programs. To this end, the German Federal Ministry of Education and Research launched the initiative "iMOVE" to introduce interested parties abroad to the range of programs and services offered by more than 20,000 public, private and non-profit German education-providers. At the same time, "iMOVE" advises education-providers on how to open up new regional markets worldwide. German education exports have become a profitable sector with an annual volume of 0.7 billion Euros. They have added a new facet to a traditional brand: "Training — Made in Germany."

The Special Advertising Section about Germany was initiated by the

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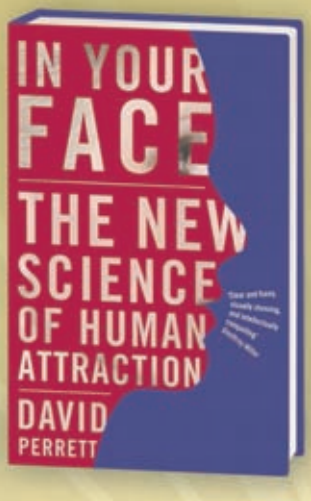

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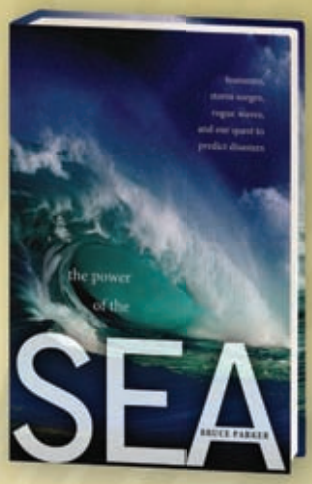

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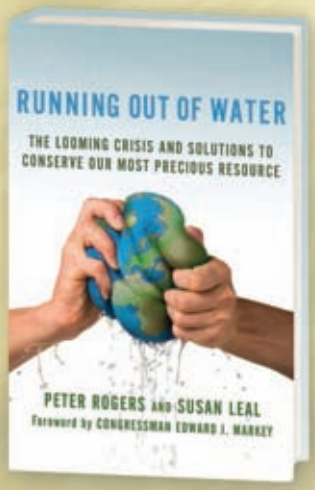

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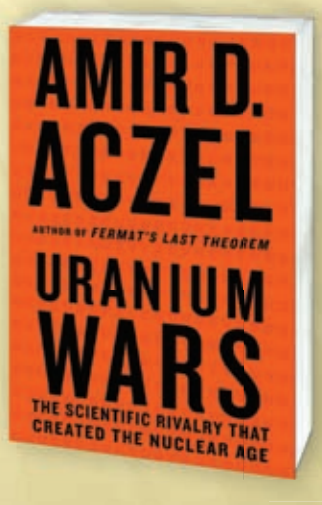

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World Changing Ideas

Ten thoughts, trends and technologies that have the power to transform our lives

TECHNOLOGY IS ALL AROUND US, EXPANDING THE LIMITS OF WHAT IS POSSIBLE. BUT EVERY ONCE in a while, some invention or insight has an outsize effect; it creates a large discontinuity, dividing history into "before" and "after." The steam engine, the transistor, the World Wide Web—each of these ideas seemed to emerge from nowhere to change our world in fundamental ways. Which key technology will arise from today's vast cauldron of innovation to become tomorrow's world changing idea? It's impossible to know, of course, but we know it will come.

Here are 10 candidates—10 new ideas and technologies that could rewrite the rules. What if we could build robots that turn waste into fuel? Or harness the power of video games (yes, video games) to make ourselves do the right thing? What if the "junk" in our DNA is actually as important as our genes? What if insects hold the secret to fending off cyberattacks? Welcome to the World Changing Ideas 2010 edition. —*The Editors*

Photograph by Mark Hooper

COMPUTING

The Game of Life

Bringing joysticks and scoreboards into our daily routine may be the key to making us better people

by John Pavlus

ONE DAY SOON, as you stand in front of the bathroom mirror brushing your teeth, you may see, alongside the morning headlines, a scoreboard that ranks your household's current carbon footprint versus your neighbors'. Your electric toothbrush will beep to notify you that dutiful brushing twice a day every day for the past six months has earned you enough points for a 10 percent discount on your next checkup. You take a shower (a brief one, so as not to jeopardize your family's enviable energy-consumption score and the tax benefits it confers), get dressed and log in at your home-office computer for the morning meeting. Now that you and your co-workers appear on-screen as personalized avatars, you can answer

your e-mail during meetings without appearing rude. And ever since arbitrary sales quotas were replaced with personalized "life meters" (which swell onscreen to reflect real-time, positive feedback from your clients), you've felt more purpose and ownership over your daily tasks. It's going to be a great day.

A future in which almost every aspect of your life includes a gamelike experience is all but inevitable, says videogame designer and Carnegie Mellon University researcher Jesse Schell. He and a bevy of game designers and psychologists are convinced that the key to a society of healthier, more productive and more engaged citizens lies in bringing gaming into daily life. "We think of games as trivial, but they're really just a way of rapidly engaging our problem-solving abilities," Schell says. "If the game is designed well enough, any problem can go in there," from changing your diet or learning a new language to understanding Middle East conflicts or reducing your carbon footprint. "These are problems that many of us can't or don't want to engage with, but games can change that because, by definition, any successful interactive system will make people *want* to engage."

An essential ingredient of this new game of life is the proliferation of real-time data from GPS-enabled mobile devices, cheap networked sensors and other technologies. "All of this personalized data lets us start measuring behaviors that we could only measure in games or virtual worlds before," says Dan Ariely, a behavioral economist at the Massachusetts Institute of Technology. "We can see what motivates and engages people in great detail and apply that knowledge to things that people don't often find engaging, like remembering to take medication or keeping track of energy use."

"Game-ifying" a real-world system still requires more than just adding avatars and points. It requires fast, personalized feedback. Effective games "harness basic human motivational tendencies in elegant ways," points out clinical psychologist Richard Ryan. Points, for example, aren't rewards as much as a method of supplying real-time feedback for building competence. "Human beings are curious animals with a natural drive to play and master their environments," Ryan observes. "Games do a good job of tapping into the intrinsic motivation that's built into us by evolution." According to psychologists, tapping those intrinsic incentives makes us feel as though we're in control and that our actions have understandable consequences.

Yet games that work well in theory can quickly turn frustrating and counterproductive, Schnell admits. He even has a name for a future in which this kind of motivational backfiring becomes common: "the gamepocalypse." The best insurance against it, he says, is to build bridges between talented game designers and technology leaders outside the entertainment field. Psychologist and games expert Byron Reeves agrees: "There are no psychological mechanisms that work for games that don't work in real life. We have only one brain. The reward centers that are lit up by well-designed games will light up when we engage with any well-designed interactive system. They don't have to be labeled 'games' with a capital 'G.'"

That's why researchers are optimistic about game-ification as a means of radically improving our world. Microsoft has used a gamelike program to increase employee retention in one division by 50 percent. First Things First, an experimental math curriculum used in five schools in Kansas and Texas, presents high school algebra and geometry as a series of 101 levels, encouraging students to master basic concepts at their own pace before moving up, as in a video game. In the four years since the program was implemented, all five schools have seen students register double-digit increases in state math tests; students at one school improved their scores by nearly 40 percent. Ryan is collaborating with Immersyve, a health care game consultancy, on creating a "virtual clinician" that uses an avatar-driven interface to make patients feel less intimidated when seeking medical consultations.

"The game-ification of everything is not going to happen because of one system—it's going to be a million different innovations in hundreds of directions, every time some new sensor gets invented," Schell says. Each one making us a little bit better.

COMPUTING

Human Number Crunchers

When research is like a video game, computers finish second *by John Pavlus*

FOR YEARS the conventional wisdom on the relative cognitive strengths of humans and machines has held that humans excel at recognizing faces and other kinds of pattern matching, while computers rule on anything that smacks of number crunching. That may no longer be the case. The success of Foldit—an online puzzle created by biologists and computer scientists at the University of Washington—proves that human intuition can outperform computer algorithms on complex scientific problems.

Foldit presents players (all nonscientists) with a partially folded protein onscreen and challenges them to twist it into an ideal shape based on simple rules. Not only did players predict correct protein structures much more quickly than any algorithm could (a brute-force search of all the possibilities would take millions of years), they were also able to intuit solutions that a computer might never have found at all. "To fold a protein into the right shape, you might first have to bend it in a couple of directions that seem totally wrong," says Seth Cooper, a Washington computer scientist and one of Foldit's inventors. "A human being playing with a virtual object can see the big picture and recognize those tricky solutions."

At the university's Center for Game Science, Cooper and his colleagues are now developing a new wave of games to accelerate the pace of research in bioinformatics, drug discovery and even nanoengineering. "Right now there are only 15 people in the world who know how to design a molecular machine out of DNA," says Washington computer scientist Zoran Popović. "These games could increase that number by two orders of magnitude—we'd have thousands of people making new discoveries." Could a gamer one day share a Nobel Prize? Says Cooper, "That's our greatest hope."

TRANSPORTATION

Know-It-All Toll Roads

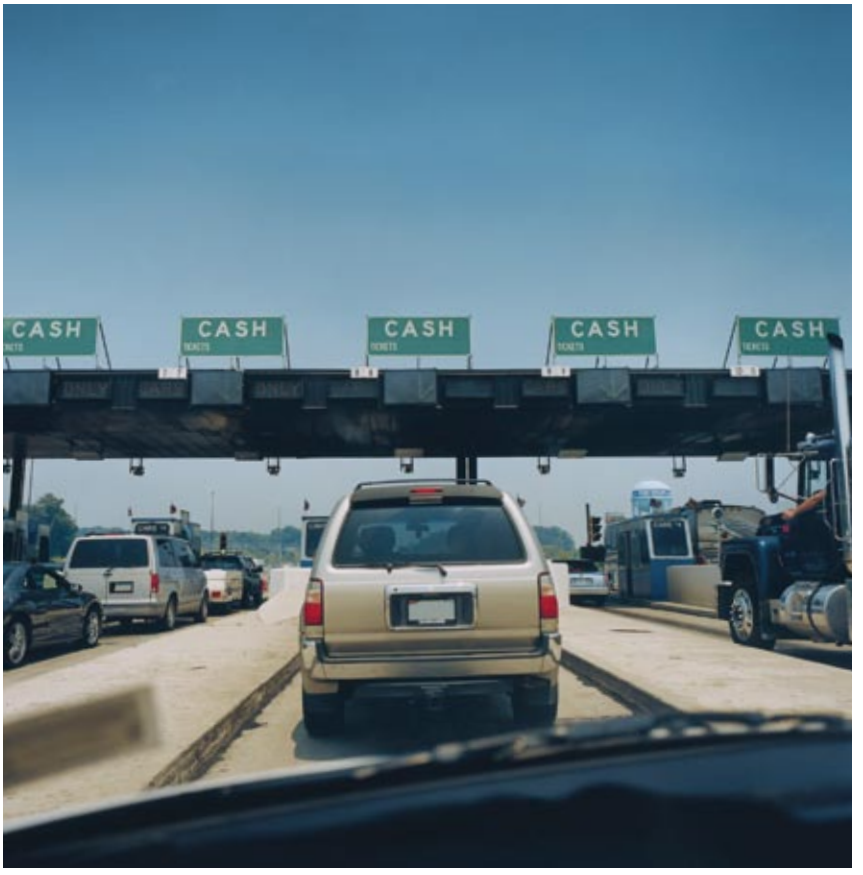
Building more roads won't eliminate traffic. Smart pricing will

by Tom Vanderbilt

THE ROAD OF THE FUTURE will look much like the road of the present, but it most certainly won't be free. "You can have your driveway," says Bern Grush, founder of Skymeter, a Toronto-based company that creates GPS-enabled devices to measure road use. "But if you're going to come over to visit me, you need to pay to get to my place from your place."

With the emergence of wireless, location-based technologies such as GPS, it is now possible to gauge the true costs of driving and the true value of the roads. The umbrella term is dynamic road-use charging, which means essentially that drivers will pay for roads they use by the mile, rather than through other mechanisms such as registration fees or a gas tax. Only a few pilot programs are up and running at the moment, but urban planners think the idea could change our experience of driving from white-knuckled frustration to something closer to a joyride. Researchers at the Massachusetts Institute of Technology and General Motors laid out such a vision earlier this year in "Reinventing the Automobile," a study that argued that transparent trip pricing would optimize road use, reducing traffic congestion and highway deaths.

Shifting the true cost of driving onto the driver would be a radical departure from what goes on now. Drivers pay no more to use crowded roads than empty roads, a person who drives once a month pays as much in insurance as someone who drives every day, and parking meters cost the same during the busiest times as during the most quiet. The federal gas tax, which for a century has financed U.S. highways, has effectively dropped from a peak of 3.9 cents per mile (2007 dollars) to 0.9 cents today, writes Cato Institute analyst Randal O'Toole in his book *Gridlock: Why We're Stuck in Traffic and What to Do about It*. As a result, congestion levels have risen steadily in the cities and suburbs. As Harvard University economist Edward Glaeser notes, you can ration scarce goods—like urban roads—by price or by queue (also known as sitting in traffic). So far the de facto choice has been traffic.



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Results from the first pilot studies have been encouraging. The Dutch government plans to enact countrywide GPS-based "per kilometer" pricing on all roads in the Netherlands by 2016. A six-month pilot trial in Eindhoven last year showed that 70 percent of users changed their behavior as a result of pricing, by traveling either at off-peak hours or on less crowded roadways. Once the program is expanded to the rest of the country, the Dutch government expects a 58 percent reduction in traffic delays.

Per-mile pricing programs can also be used to benefit the environment. In Germany, where heavy trucks are charged not just by the mile but by their emissions (dirtier trucks pay a higher per-mile fee), the percentage of trips driven by low-emissions trucks has jumped from less than 1 percent in 2005, when the program began, to more than 55 percent.

The collapse of the Dutch government earlier this year, however, has put the future of its road-pricing program in doubt—a reminder that politicians want to be seen building new roads, not new tollbooths. The technology required can also be prohibitively expensive. In one trial, U.K. insurer Norwich Union (now known as Aviva) used on-car gadgets to measure not only where and when young drivers drove but *how* they drove. The company used in-car accelerometers to punish aggressive drivers with higher insurance rates. Even though accident claims dropped by 30 percent during the trial, the required telematics were too expensive to make the program sustainable.

Smart tolls can help alleviate another cause of urban traffic: street parking. Researchers such as Donald Shoup of the University of California, Los Angeles, argue that underpriced street parking leads to urban congestion as drivers cruise for bargains. To avoid this practice, San Francisco is implementing "dynamic parking," which uses sensors to track a car's presence in a parking spot and tally overall demand; the city then sets prices at a level that ensures a constant 85 percent occupancy. The rates can change by time of day and day of the week, although they will always be set in advance—making them much easier to predict than the amount of time you would otherwise be wasting in traffic.

BIOTECHNOLOGY

The DNA Transistor

A new approach to DNA sequencing could revolutionize our understanding of genetics *by Elizabeth Svoboda*

IN THE DECADE since researchers first sequenced the human genome, obvious links between the genes and individual diseases have been slow to appear [see "Revolution Postponed," by Stephen S. Hall; SCIENTIFIC AMERICAN, October]. Many researchers now believe that real advances in genomics will come not from simple X-causes-Y correlations but from a rich statistical understanding that emerges out of the sequences of millions of genomes—a set that reveals how our genetic code is likely to interact with the environment to make us who we are.

This, in turn, requires a cheap genome sequencer, something that can do the job for less than $1,000. Right now it costs between $5,000 and $15,000 to sequence a genome—a great improvement from the $2.7 billion it originally cost but still far from the goal. Researchers at IBM and Roche are trying to get there by undertaking a radical redesign of gene-sequencing machines. Whereas existing dishwasher-size sequencers require expensive chemical reagents to analyze genes that have been sliced into thousands of small fragments, the so-called DNA transistor takes an almost naively simple approach. In it, an intact DNA molecule threads through a three-nanometer-wide gap in the middle of a silicon chip. As the DNA feeds through the nanopore, an electrical sensor reads it one molecular unit, or base, at a time.

Other labs have experimented with similar nanopore-based approaches to sequencing but have found it difficult to control how quickly the DNA strand feeds through the nanoscale hole. The IBM team has hit on a method that capitalizes on DNA's naturally occurring negative charge. "We thought that if the device contained electrodes in the pore itself—thin layers of metals separated by insulating material—that electric field would interact with the DNA," says Gustavo A. Stolovitzky, a research scientist working on the project. The electric field grabs the negatively charged DNA and holds it in place. When the electric field shuts off, the strand continues to move through the hole until the next base lines up for sequencing. At that point the electric field reappears, and the process repeats itself all the way down the strand.

The technique isn't a slam dunk. The pore must produce a strong electric field to hold the DNA in place. But the high voltage needed to create this field can cause what is known as a dielectric breakdown, where sparks fly and the electric field shorts out, which is especially likely to happen over such short distances. "It's as if you have a cloud very close to the earth—it's much easier for lightning to strike," Stolovitzky says. The researchers are looking for an electrode material that can withstand the necessary charge.

Despite these issues, industry observers think the DNA transistor can be a fast, cheap, efficient way to sequence genomes. "This reduces the number of steps required for sequencing—it's just literally looking at the DNA itself," says Bruce Schiamberg, a consultant who evaluates the commercial potential of biotechnology innovations. "There are no reagent costs or optical instruments needed to read fluorescent tags. The thing gets done faster."

The DNA transistor is on track to supply a complete genome sequence within the next few years for less than $1,000. Stolovitzky believes the device will help the scientific community more readily make connections between genes, health vulnerabilities and ideal drug treatments. With a statistical understanding of the connections between genes and disease, pharmaceutical companies could better target drug development, because they would already know what regions their new drugs would need to focus on. He points to one of the early success stories: herceptin, a breast cancer treatment that halts tumor growth in patients who show overexpression of a gene called *HER2*. "There are a handful of these examples," Stolovitzky says. "We would like for it to become a very common thing."

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HEALTH AND MEDICINE

A Killer Water Filter

Novel materials promise better access to clean water around the world

by Melinda Wenner Moyer

ONE IN SIX PEOPLE lacks access to clean water worldwide, making diarrheal illness—a direct result of poor sanitation—the leading cause of death globally. Water filters would do the trick, but they are generally too expensive to distribute in great enough quantities. By combining nanotechnology with cheap materials such as cotton and tea bags, however, researchers have recently developed mobile water filters that can be manufactured for less than a penny.

Most conventional water filters are equipped with small pores that "trap" bacteria, but the pores have a tendency to get clogged, which requires expensive maintenance. Yi Cui found a way to use silver and electricity to kill the bacteria instead. Cui, a materials scientist at Stanford University, dipped woven cotton that he purchased at Walmart into a mixture of electrically conducting carbon nanotubes and silver nanowires. Silver works as an effective bactericide in part because silver ions damage genetic material. Additional killing power comes from a light electric current (powered by two nine-volt batteries) that breaks the bacterial cell membranes. In the lab, Cui's filter killed more than 98 percent of E. coli bacteria in water. Because the pores in the cotton are large, the filter is 80,000 times faster than filters that trap microbes.

An even cheaper invention is a kind of a tea bag filled with carbon granules coated with a microbicide. Researchers at South Africa's Stellenbosch University figured out a way to encapsulate the chemicals within nanofibers to increase their surface area and help them trap toxic substances and bacteria. The filter fits in the neck of an ordinary bottle and costs about half a U.S. cent apiece. Each bag is good for cleaning one liter of polluted water. The technology is currently being tested by the South African Bureau of Standards, after which the researchers plan to dole it out to communities in need.

ROBOTICS

A Wandering, Plant-Eating Robot

It gobbles up wood chips, leaves and other "biomass" and generates electricity *by John Pavlus*

THE DAY COULD SOON come when autonomous robots roam the planet in search of raw biomass to consume for power. Such is the vision of the Energetically Autonomous Tactical Robot system, although you can call it EATR. "Imagine the robot in the movie *WALL-E*—but instead of just compacting trash, it's combusting trash for electrical energy," says Robert Finkelstein, director of the Intelligent Systems Laboratory in the Clark School of Engineering at the University of Maryland and president of Robotic Technology, the company developing EATR. The robot uses intelligent software to visually distinguish its preferential "food"—wood chips, dried leaves and other vegetative biomass—from nonuseful materials such as rocks, animal matter and metal. Then, using a robotic arm guided by a close-range laser-based guidance system, EATR grabs the vegetation and places it into a hopper leading to an external-combustion engine, which charges an onboard battery.

Such self-directed power generators could revolutionize many military, civilian and even scientific operations, Finkelstein says. "In the next few years every U.S. soldier will use the equivalent of 120 AA batteries every day to power his communications and support equipment," he says. "Using an EATR would greatly reduce the logistical burden of supplying that energy in remote locations, because [the robot] can be out consuming vegetation while the rest of the unit rests." Funding for EATR comes from the Defense Advanced Research Projects Agency.

Veggie-eating robots could also be put in service of the environment. The U.S. Forestry Service wants an EATR mounted on legs, rather than on a Humvee. In that way, it can wander the countryside in search of invasive plant species without leaving treadmarks. "The legs would let it negotiate uneven terrain without damaging that terrain as much as tires or treads would," Finkelstein says.

EATR is currently confined to a stationary test platform at the University of Maryland, but Finkelstein expects a fully mobile, foraging model to be operational sometime in 2012. The prospect sounds creepy, but he believes that a world in which robots are self-sufficient is not only desirable but inevitable. "We already have household robots that can plug themselves into an outlet to recharge without bothering us," Finkelstein says. "This is just the same idea, taken to the next level."

GETTY IMAGES

COMPUTING

Borrowing Nature's Code

Algorithms inspired by Mother Nature help us run our vast digital biosphere *by John Pavlus*

AS COMPUTER SCIENTISTS try and figure out how to manage an increasingly complex digital world, they are increasingly turning for inspiration to Mother Nature. "Life runs on sunlight and information," says Janine Benyus, president of the Biomimicry Institute in Missoula, Mont. A species is constantly evolving to find the optimal way to survive in a particular habitat. "Organisms really do lend themselves to people looking for novel ways to solve information-processing problems," she says.

Dendritic cells, for instance, would seem at first glance to have nothing to do with computer security. But these cells are Paul Reveres of the mammalian immune system, sounding the alarm on invading pathogens. Computer scientist Julie Greensmith of the University of Nottingham in England designed a "dendritic cell algorithm" that detects computer viruses and other malicious code in the same way that our immune systems sense real viruses.

Ants and other social insects have inspired another team of cybersecurity researchers, at Pacific Northwest National Laboratory in Richland, Wash. They have created "digital ants" that can roam a computer network the same way that real ants patrol a nest and quickly swarm around any perceived threat.

Such "bioinspired" algorithms are as old as Turing machines and other classical models of computation, says Melanie Mitchell, a computer scientist at Portland State University. But in a Web-connected world increasingly saturated by "Big Data"—hundreds of exabytes of information are generated every year—code based on nature may be the best way to deal with the load. "There's a huge amount of interest in new collaborations between biological and computer sciences because people are realizing that computation goes beyond what we call 'computers,'" Mitchell explains. "One of the main things that all these biological systems do so well is pattern recognition—pulling signal out of the noise even when they're inundated with information. Brains do it, individual cells do it, insect colonies do it—that's what *all* biological systems do in order to live. And we'd like computers to do that, too."

Photograph by Mark Hooper

HEALTH AND MEDICINE

One Hundred Tests

A cheap diagnostic warns couples against passing rare genetic diseases to their offspring *by Mary Carmichael*

WHAT WOULD YOU PAY to ensure that your children would not be born with disabling or fatal recessive genetic diseases? The obvious answer is "anything," but that's not what most people actually do. Individual screening tests can already identify silent carriers of many single faulty recessive genes—the kind that, when inherited in double (one copy from each parent), can lead to conditions such as cystic fibrosis and Tay-Sachs disease. But almost no one gets tested for all these mutations before conceiving because it would be too expensive—the dozens of tests cost several hundred dollars apiece. Because each potentially dangerous mutation is rare, most people choose instead to play the odds and hope their children will be healthy—a strategy that sometimes results in tragedy.

That isn't necessary anymore, thanks to a simple saliva test made by a company called Counsyl that interrogates the genome for more than 100 disease-causing recessive traits. In one sense, it is like having many traditional, separate tests combined; from a medical standpoint, it yields essentially the same results. But it does so in one go, at a cost of $350.

Traditional tests for recessive variants work by zooming in on specific genomic regions associated with each disease. In some cases, the tests sequence the genes to determine if mutations are present. Counsyl's test, on the other hand, does not involve sequencing. Instead it looks for single-nucleotide polymorphisms (SNPs), tiny typos in the genome where one base has been replaced with another. Some SNPs contribute to disease; others are linked to genes that do. Because SNPs are small, it is cheaper to identify one of them than it is to sequence an entire gene or region of a chromosome, which may consist of millions of bases. The company says the test picks up mutations with greater than 99 percent sensitivity and specificity—that is, it rarely yields false positives or negatives—and has recently begun to publish results to that effect.

So far Counsyl's test has mostly been used by infertility patients. Pasquale Patrizio, director of the Yale Fertility Center, is one of the doctors offering it. (He is also on Counsyl's board of advisers.) He says it is useful in treating couples who have suffered repeated miscarriages but do not know why. In some cases, their losses may turn out to be caused by recessive genes that prevent the fetus from coming to term. "For us it was really a breakthrough to have such a comprehensive screening test," Patrizio says. But of course, many people who carry recessive genes manage to conceive without the assistance of a fertility clinic. They find out about their genetic bad luck later, once their children become ill.

Couples who test positive can plan ahead. They might choose in vitro fertilization, combined with preimplantation genetic diagnosis, to choose embryos that do not carry disease genes. Or they might decide to adopt. Either way, the numbers of ill children in the population at large would drop. Most of the double-recessive diseases are research "orphans"; because they are rare, little money is put into studying them. The Counsyl test is the best present hope for ensuring that fewer people are afflicted with them.

Counsyl may run into some roadblocks on its way to wide use. Some people fear it will open the door to "designer babies." Widespread testing for rare genetic diseases, the argument goes, opens the door to testing for traits that do not indicate disease, such as height and intelligence.

Counsyl's technology can't produce designer babies, however, because it tests for single genes, not the poorly understood, multilevel genetic networks involved in complex phenomena such as intelligence. "There isn't going to be an IQ gene or a musical ability gene," says Harvard University psychologist Steven Pinker, who is advising the company on the ethical issues surrounding personal genomics. Besides, he notes, "if any group would have fears about eugenics it would be the Jews"—yet as a group they have embraced the old, expensive recessive-gene tests because Ashkenazi Jews are more likely to carry some deleterious recessive variants. Pinker, who is Jewish, carries the one that causes familial dysautonomia, an incurable disease that halts neuron development. He found out only when he took the Counsyl test. "My wife is a carrier, too," he says. "We met too late in life to have children, but if we had met a few years earlier we would have been playing roulette." At least now other couples can choose not to.

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Gas from Trash

Modified microbes eat waste and "secrete" fuel

by Matthew L. Wald

TODAY THE FACTORIES THAT MAKE GASOLINE, diesel and jet fuel are huge clusters of steel pipes and tanks that consume prodigious amounts of energy, release toxic fumes, and run on an exhaustible resource, petroleum. But tomorrow they might be microscopic, and they might run on the garbage hydrocarbons that are all around us—the paper of this magazine, scrap lumber from a construction project, or the leaves you raked off your lawn last month.

The trick is to transform the hydrogen- and carbon-based molecules inside these everyday items into a liquid at room temperature, thus making them suitable for use in internal-combustion engines. The most promising efforts involve genetically modifying single-celled organisms to do this conversion work for us. Many of these organisms already build hydrocarbons out of raw materials found in the environment, though not in a way that makes the product available for human use. For example, algae are very good at turning carbon dioxide into fatty acids that can be refined into fuel, but getting the algae out of the water and the fatty acids out of the algae requires so much effort that the process is mostly used for pricey products, such as cosmetics.

A better solution would be to create organisms that directly "secrete" the hydrocarbon. (Commercial firms understandably don't like the more accurate, but less pleasant, "excrete.") With an organism that secretes, "you transform biomass from something you harvest into something that comes from little chemical factories," says Eric Toone, an Energy Department official in charge of making grants to companies with novel biofuel ideas.

Creating genetically modified fuel factories raises other complications, however. Many people worry about engineered organisms finding their way into the environment; vats of single-celled bugs would be almost impossible to contain.

The organisms must also be kept well fed—the question is with what? One approach is to use sunlight. In September, Joule Unlimited, a biotechnology start-up in Cambridge, Mass., won a patent for a gene-altered bacterium that uses sunlight and carbon dioxide to create components of diesel fuel.

Another strategy is to use sugars. When plants capture energy, they chemically lock up that energy in sugars located in the woody portion of the crop. Many researchers are devising ways to recover the sugars from these "cellulosic sources" and turn them into ethanol, which gets a tax credit but has a lower energy density than gasoline and does not run well in conventional cars at high concentrations.

Instead scientists and engineers hope to make more useful chemicals directly from those sugars. In July scientists at LS9, a company in South San Francisco, said they had modified *E. coli* bacteria to enable the organisms to convert sugars into alkanes, a class of hydrocarbon that is identical to many of the molecules produced in standard oil refineries. With a few more tweaks to the genome, the fuel in your tank could even come from sugars pried from the scrap heap.

Photograph by Mark Hooper

HEALTH AND MEDICINE

The Importance of Junk DNA

Biologists continue to be surprised by what was once dismissed as wasted space *by Melinda Wenner Moyer*

GENES MAKE UP ONLY ABOUT 2 PERCENT of the human genome. The rest was for many years ignored as "junk DNA." But over the past decade biologists have come to understand that this space is an incredibly important part of the genetic code, home to a vast unexamined treasure trove of information that controls how genes behave. A more thorough investigation of junk DNA could upend our understanding of the delicate interplay between genes and the environment and could lead to entirely new strategies in medicine's endless struggle against disease.

New examples of junk DNA's importance seem to emerge every few months. Researchers publishing in the September issue of *Nature Medicine* reported that the rare nervous system cancer neuroblastoma may in part have junk DNA to blame; a small piece of RNA made from junk DNA disables a cancer-inhibiting gene in people suffering from the disease. Similarly, those afflicted with a rare form of muscular dystrophy have between one and 10 copies of a particular slice of junk DNA on the end of the fourth chromosome. Junk DNA isn't just relevant for rare diseases, either: this past February a paper in *Nature* linked a region of junk DNA on the ninth chromosome to heart disease risk.

Junk DNA may also help organisms adapt to changing environments. In May 2009 scientists at the University of Leuven in Belgium reported that gene activity on a yeast chromosome is directly controlled by the number of repeats in a section of junk DNA. Because the number of repeats changes more frequently than other stretches of DNA do, this setup allows the organism to evolve more quickly.

So does junk DNA deserve a new, more respectful name? Scientists disagree. Some junk DNA may be obviously useful, but the potential benefits of the rest "may be much more subtle and hard to trace," says Kevin Verstrepen, a co-author of the yeast study. In time, though, one biologist's junk may turn out to be another's jewel.

WORLD CHANGING VIDEOS

Wheelchairs and windmills are among the winners of the 2010 World Changing Ideas Video Contest, sponsored by *Scientific American* and SciVee.tv, the online science video site. The entries showcase innovative ways to build a cleaner, healthier or safer world.

WINNER

The Leveraged Freedom Chair
Idea: MIT Mobility Lab
Video: Amos Winter and the MIT News Office
This wheelchair features a lever-powered, geared drivetrain that takes it over sand, dirt and rough terrain often confronted in developing countries. The judges hailed it as "ingenious, simple and doable now. It could change one person's whole world."

RUNNERS-UP

Sourcemap
Idea and video: Leonardo Bonanni
His crowdsourced Web site tracks the environmental footprint of product supply chains.

Urban Power
Idea: Mark Maynard
Video: Michael Garjian
This backyard wind turbine generates electricity in slow as well as fast breezes.

FIND ALL THE WINNING VIDEOS
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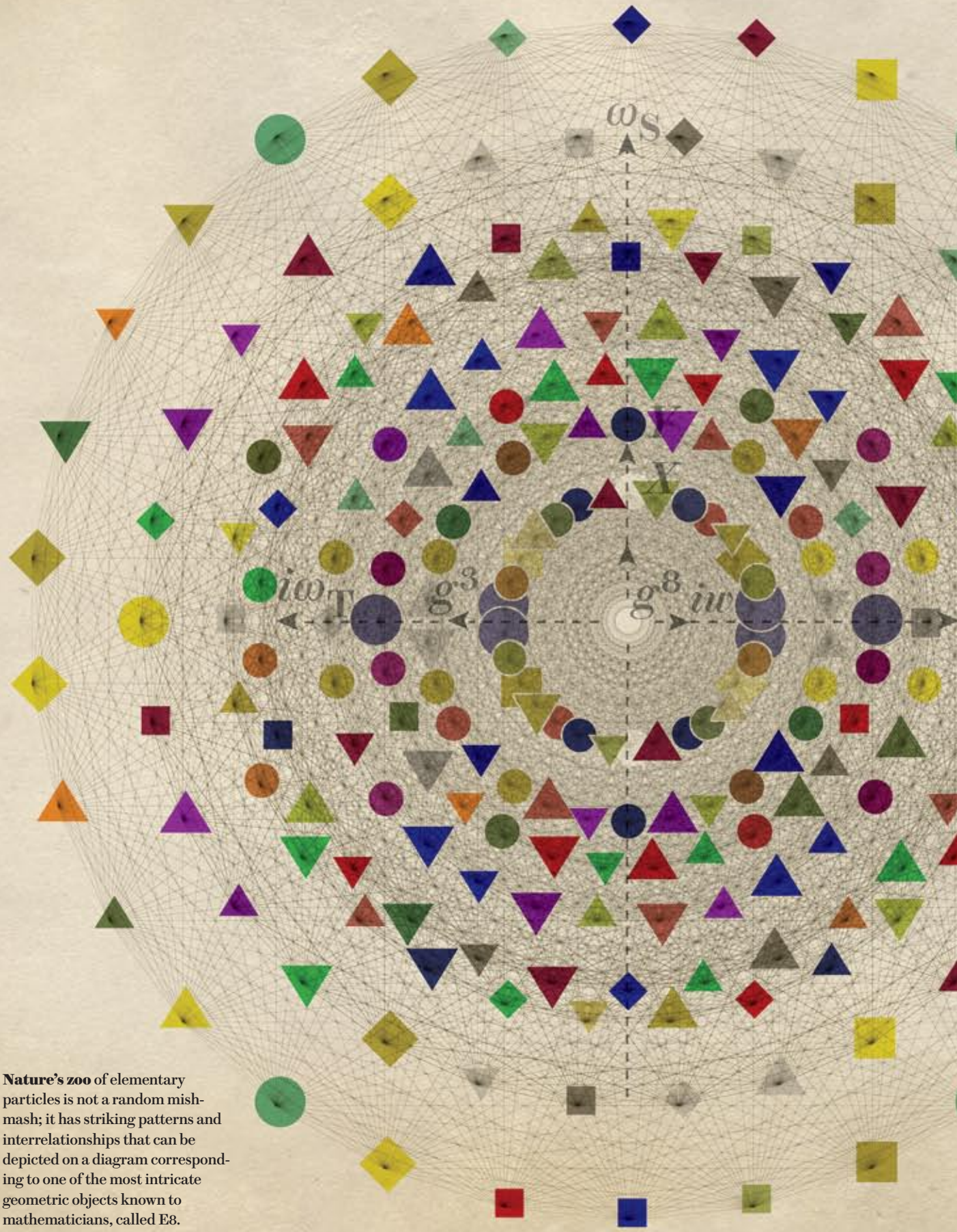
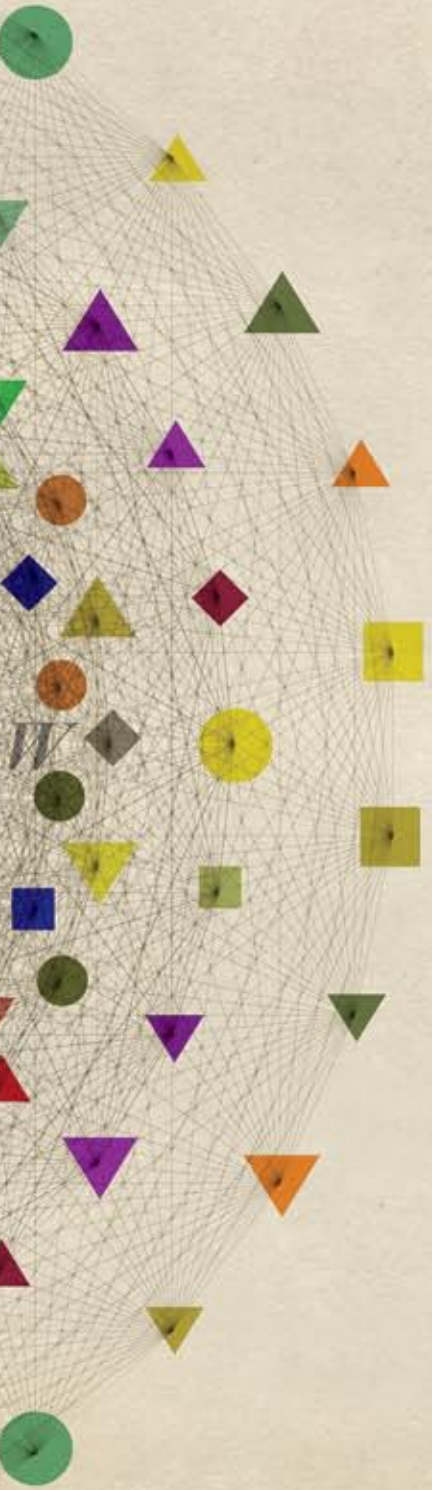


Nature's zoo of elementary particles is not a random mishmash; it has striking patterns and interrelationships that can be depicted on a diagram corresponding to one of the most intricate geometric objects known to mathematicians, called E8.



A. Garrett Lisi balances his time between research in theoretical physics and surfing. As an itinerant scientist, he is in the process of realizing a lifelong dream: founding the Pacific Science Institute, located on the Hawaiian island of Maui.

James Owen Weatherall, having recently completed his doctorate in physics and mathematics at the Stevens Institute of Technology, is now finishing a second Ph.D. in philosophy at the University of California, Irvine. He also manages to find time to work on a book on the history of ideas moving from physics into financial modeling.

PHYSICS

A Geometric Theory of Everything

Deep down, the particles and forces of the universe are a manifestation of exquisite geometry

By A. Garrett Lisi and James Owen Weatherall

MODERN PHYSICS BEGAN WITH A SWEEPING UNIFICATION: IN 1687 ISAAC Newton showed that the existing jumble of disparate theories describing everything from planetary motion to tides to pendulums were all aspects of a universal law of gravitation. Unification has played a central role in physics ever since. In the middle of the 19th century James Clerk Maxwell found that electricity and magnetism were two facets of electromagnetism. One hundred years later electromagnetism was unified with the weak nuclear force governing radioactivity, in what physicists call the electroweak theory.

This quest for unification is driven by practical, philosophical and aesthetic considerations. When successful, merging theories clarifies our understanding of the universe and leads us to discover things we might otherwise never have suspected. Much of the activity in experimental particle physics today, at accelerators such as the Large Hadron Collider at CERN near Geneva, involves a search for novel phenomena predicted by the

IN BRIEF

In 2007 physicist A. Garrett Lisi wrote the most talked about theoretical physics paper of the year. Outlets from the *New Yorker* to *Outside* magazine were drawn to the story, partly on account of his surfer lifestyle. Lisi and others have continued to develop the theory.

Most physicists think reconciling Einstein's general theory of relativity with quantum theory will require a radical shift in our conception of reality. Lisi, in contrast, argues that the geometric framework of modern quantum physics can be extended to incorporate Einstein's theory, leading to a long-sought unification of physics.

Even if Lisi turns out to be wrong, the E8 theory he has pioneered showcases striking patterns in particle physics that any unified theory will need to explain.

Illustrations by Chad Hagen

unified electroweak theory. In addition to predicting new physical effects, a unified theory provides a more aesthetically satisfying picture of how our universe operates. Many physicists share an intuition that, at the deepest level, all physical phenomena match the patterns of some beautiful mathematical structure.

The current best theory of nongravitational forces—the electromagnetic, weak and strong nuclear force—was largely completed by the 1970s and has become familiar as the Standard Model of particle physics. Mathematically, the theory describes these forces and particles as the dynamics of elegant geometric objects called Lie groups and fiber bundles. It is, however, somewhat of a patchwork; a separate geometric object governs each force. Over the years physicists have proposed various Grand Unified Theories, or GUTs, in which a single geometric object would explain all these forces, but no one yet knows which, if any, of these theories is true.

And an even deeper unification problem faces today's physicists. In a fully unified theory, gravity and matter should also combine naturally with the other forces, all as parts of one mathematical structure—a Theory of Everything. Since the 1980s string theory, the dominant research program in theoretical particle physics, has been an attempt to describe gravity and the Standard Model using elaborate constructs of strings and membranes vibrating in many spacetime dimensions.

But string theory is not the only effort. An alternative, loop quantum gravity, uses a more minimal framework, closer to that of the Standard Model [see "Atoms of Space and Time," by Lee Smolin; Scientific American, January 2004]. Building on its insights, one of us (Lisi) proposed a new unified theory in 2007. The basic idea is to extend Grand Unified Theories and include gravity as part of a consistent geometric framework. In this unified field theory, called E8 theory, all forces and matter are described as the twisting of a single geometric object.

All new ideas must endure a trial by fire, and this one is no exception. Many physicists are skeptical—and rightly so. The theory remains incomplete. But even in this early stage of development, it unveils some of the beautiful structures in play at the deepest levels of nature, and it makes predictions for new particles that the Large Hadron Collider might find. Although physicists are not yet at the culmination of our centuries-long quest for unity, E8 theory is an important step on that journey.

EVERY FIBER OF OUR BEING

TO DESCRIBE E8 THEORY, we first need to set out the widely accepted geometric principles that govern all known forces and particles. Geometry is the study of shape, but in the case of fundamental physics, you might wonder: shape of what? Plato thought elements such as earth and air were associated with little cubes and octahedra. Similarly, in modern physics, the geometric objects associated with elementary particles are perfect, smooth shapes, existing outside our space yet connected to it. We cannot see these shapes directly, but we see their effects.

The main geometric idea underlying the Standard Model is that every point in our spacetime has shapes attached to it, called fibers, each corresponding to a different kind of particle. You can envision the universe as a Chia Pet (a terra-cotta figurine covered with sprouts). The surface of the figurine is analogous to spacetime, and the sprouts are fibers. The entire geometric object—spacetime and fibers together—is called a fiber bundle. The fibers are not in our space, but over it; they may be thought of as different, internal spaces attached to each point of our spacetime, with shapes corresponding to particles' properties.

This idea, introduced in 1918 by mathematician Hermann Weyl, is now a well-established principle of physics [see "Fiber Bundles and Quantum Theory," by Herbert J. Bernstein and Anthony V. Phillips; Scientific American, July 1981]. Distinct from the speculated undulating spatial dimensions of string theory, these internal space fibers are of fixed shape. Their dynamics arise from how they are attached to four-dimensional spacetime.

The electric and magnetic fields existing everywhere in our space are the result of fibers with the simplest shape: the circle. A circle, called U(1) by physicists, is the simplest example of a Lie group (pronounced "Lee," after 19th-century Norwegian mathematician Sophus Lie). It has a single symmetry: if we rotate a circle, it remains the same. A small rotation like this is called a generator of the Lie group. Following a generator, just like drawing with a compass, takes us around a circle.

The fiber bundle of electromagnetism consists of circles attached to every point of spacetime [*see box on opposite page*]. Crucially, each circle can rotate a little relative to its spacetime neighbors. The so-called connection field of a fiber bundle describes how neighboring fibers are related by these symmetry rotations. The electric and magnetic force fields filling spacetime correspond to the curvature of this fiber bundle—geometrically, the electric and magnetic fields are how the circular fibers twist over time and space. An electromagnetic wave is the undulation of circles over spacetime. One quantum of an electromagnetic wave—a photon—is a propagating particle of light.

Each kind of elementary particle corresponds to a different fiber over spacetime; the Chia Pet has many different kinds of sprouts. All the electrons of the world result from the twisting of a single kind of fiber—explaining, among other things, why all electrons are identical. The fibers of electrically charged particles, such as electrons, wrap around the circular fibers of electromagnetism like threads around a screw. How fast a particle's fiber twists around the circle is equal to its electric charge, determining how the particle responds to the force of electromagnetism.

Because twists must meet around the circle, these charges are integer multiples of some standard unit of electric charge. Of the elementary matter particles, called fermions, electrons have electric charge –1 (three twists), up quarks have electric charge +⅔ (two opposite twists), down quarks have electric charge –⅓ (one twist), and neutrinos have 0. The antimatter particles, such as positrons and antiquarks, have twists in the opposite direction around the electromagnetic circle, giving them the opposite electric charges.

When particles collide, they may be converted into new types, but the outgoing particles have exactly the same total charge as the incoming ones did. This crucial fact is a consequence of fiber geometry: When any two particles meet, their twists add. In this way, the fiber-bundle picture explains what we know about electromagnetism. The electric charges describe the geometric structure of the combined electromagnetic and matter fiber bundle, determining what interactions are possible between electrically charged particles.

DIFFERENT CHARGES FOR DIFFERENT FORCES

PHYSICISTS APPLY these same principles to the weak and strong nuclear forces. Each of these forces has its own kind of charge and its own propagating particles. They are described by more

complicated fibers, made up not just of a single circle but of sets of intersecting circles, interacting with themselves and with matter according to their twists.

The weak force is associated with a three-dimensional Lie group fiber called SU(2). Its shape has three symmetry generators, corresponding to the three weak-force boson particles: W^+, W^- and W^3—relatives of the photon. Each Lie group is a multidimensional, smooth tangle of intersecting circles twisting around one another. The circles of the W^+ and W^- bosons in SU(2) twist oppositely around the W^3 circles and so have weak charge, W, of +1 and –1. Because they have weak charge, these particles interact with one another as well as with matter.

Exactly half of elementary matter particles interact with the weak force, their fibers twisting around the W^3 and other circles of SU(2). Fermions come in two varieties, related to how their spin aligns with their momentum: left-handed and right-handed. Only the left-handed fermions have weak charges, with the left-handed up quark and neutrino having weak charge +½ and the left-handed down quark and electron having weak charge –½. For antiparticles, this is reversed: only right-handed antiparticles have weak charge. In other words, our universe is not left-right symmetrical—we can tell whether we are looking at weak interactions directly or looking at them in a mirror. This asymmetry is one of many mysteries a unified theory seeks to explain.

When physicists unified the weak force with electromagnetism to create the electroweak theory, they combined the SU(2) fiber with a U(1) circle. This circle is not the same as the electromagnetic one; it represents a precursor to electromagnetism known as the hypercharge force, with particles twisting around it according to their hypercharge, labeled Y. Inside the combined four-dimensional electroweak Lie group, the W^3 circles combine with the hypercharge circles to form a two-dimensional torus. This torus can be sliced in many ways, just as every person has their own idiosyncratic way to slice a bagel. The fibers of particles known as Higgs bosons twist around the electroweak Lie group and determine a particular set of circles, breaking the symmetry—like someone insisting there is only one true way to cut a bagel. The Higgs does not twist around these circles, which then correspond to the massless photon of electromagnetism.

Perpendicular to these circles are another set that should correspond to another particle, which the developers of electroweak theory called the Z boson. The fibers of the Higgs bosons twist around the circles of the Z boson, as well as the circles of the W^+ and W^-, making all three particles massive. Experimental physicists discovered the Z in 1973, vindicating the theory and demonstrating how geometric principles have real-world consequences.

A good way to see how the electroweak theory works is to plot the weak charges and hypercharges of all known particles [*see box on next four pages*]. Because mathematicians call charge "weight," this plot is known as a weight diagram. In this diagram, all particles line up on equally spaced oblique lines, corresponding to their electric charges. Electric charge is thus a specific combination of weak charge and hypercharge, determined by the Higgs bosons. By experimentally measuring the strength of the weak force, physicists know that the angle of these lines, known as the weak mixing angle, is about 30 degrees. Explaining the value of this angle is one of the most tangible and immediate goals of a unified theory of physics.

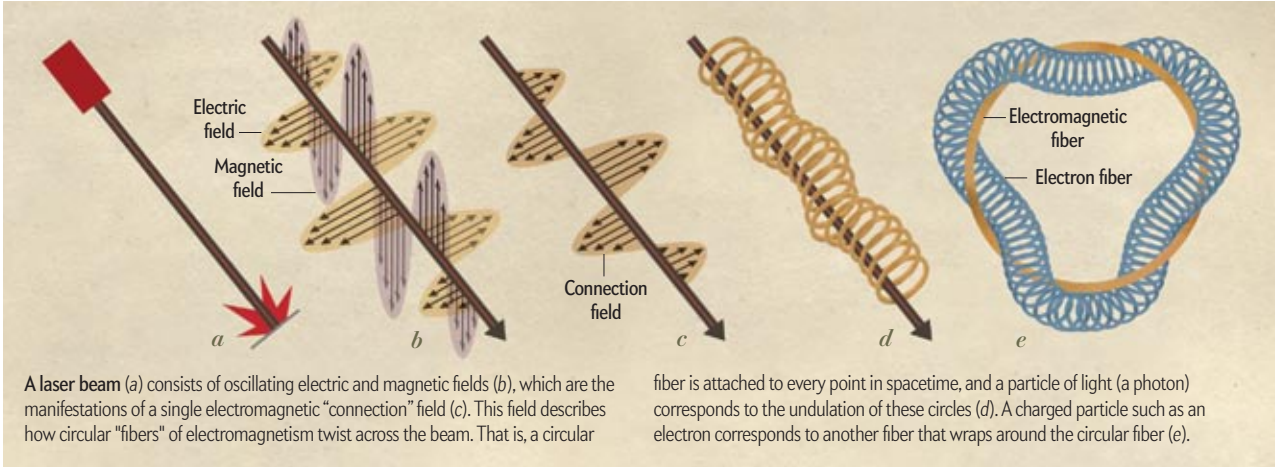
COLORFUL PHYSICS

IN THE STANDARD MODEL, the strong nuclear force that binds quarks into atomic nuclei corresponds geometrically to an even larger Lie group, SU(3). The SU(3) fiber is an eight-dimensional internal space composed of eight sets of circles twisting around one another in an intricate pattern, producing interactions among eight kinds of photonlike particles called gluons on account of how they "glue" nuclei together. As complicated as this fiber shape is, we can break it into comprehensible pieces. Em-

BASICS

From Electromagnetism to Geometry

The geometric view of nature follows naturally from the way the world around us works. The simplest and most familiar examples are the forces of electricity and magnetism. Electric sparks, magnetic attraction and laser light are different manifestations of the electric and magnetic fields that pervade space. In fact, physicists think that everything in the world—all the forces of nature and even all the particles of matter—arises from different kinds of fields. The behavior of these fields hints at an underlying geometric structure.



A laser beam (*a*) consists of oscillating electric and magnetic fields (*b*), which are the manifestations of a single electromagnetic "connection" field (*c*). This field describes how circular "fibers" of electromagnetism twist across the beam. That is, a circular fiber is attached to every point in spacetime, and a particle of light (a photon) corresponds to the undulation of these circles (*d*). A charged particle such as an electron corresponds to another fiber that wraps around the circular fiber (*e*).

bedded within it is a torus formed by two sets of untwisted circles, corresponding to two generators, g^3 and g^8. The remaining six gluon generators twist around this torus, and their resulting g^3 and g^8 charges form a hexagon in the weight diagram.

The quark fibers twist around this SU(3) Lie group, their strong charges forming a triangle in the weight diagram. These quarks are whimsically labeled with three colors: red, green and blue. A collection of matter fibers forming a complete pattern, such as three quarks in a triangle, is called a representation of the Lie group. The colorful description of the strong interactions is known as the theory of quantum chromodynamics.

Together, quantum chromodynamics and the electroweak model make up the Standard Model of particle physics, with a Lie group formed by combining SU(3), SU(2) and U(1), as well as matter in several representations. This structure is described by a weight diagram with four charge axes, which may be projected down to two dimensions and plotted. This diagram displays the crown jewels of modern physics. Every allowed particle interaction of the Standard Model may be found on it.

The Standard Model is a great success. But it presents several puzzles: Why does nature use this combination of Lie groups? Why do these matter fibers exist? Why do the Higgs bosons exist? Why is the weak mixing angle what it is? How is gravity included? And there are other mysteries we have not even touched on. The quarks, electrons and neutrinos that constitute common matter are called the first generation of fermions; they have second- and third-generation doppelgängers with identical charges but much larger masses. Why is that? And what are cosmic dark matter and dark energy? A unified theory should be able to provide answers to these and other questions. The first step toward such a theory is the unification of electroweak and strong forces.

GRAND (BUT NOT FULL) UNIFICATION

ALTHOUGH THE ELECTROWEAK and strong forces can both be described using fiber bundles, their fibers are separate. Physicists have asked whether some single fiber encompasses both. Instead of different Lie groups for each force, there would be a single, larger Lie group for all. They have good evidence for this idea: all these forces become close in strength at very short distances, indicating they are aspects of a single force. A Grand Unified Theory would describe this force, reproduce the Standard Model and make testable predictions.

In this way, investigators are trying to reproduce the earlier success of finding why the chemical elements line up in the periodic table, representing the structure of atoms. Once chemists had gleaned this structure, they began making predictions for what properties the elements should have and what new elements might await discovery. Likewise, particle physicists today are trying to find out why the weight diagram of the Standard Model has the pattern it does, and once they do, they will be able to make predictions for what properties the particles should have and what new particles might exist.

The first attempt at such a theory was proposed in 1973, by Howard Georgi and Sheldon Glashow [see "A Unified Theory of Elementary Particles and Forces," by Howard Georgi; SCIENTIFIC AMERICAN, April 1981]. They found that the combined Lie group of the Standard Model fits snugly into the Lie group SU(5) as a subgroup. This SU(5) GUT made some distinctive predictions. First, fermions should have exactly the hypercharges that they do—a highly nontrivial success. Second, the weak mixing angle should be 38 degrees, in fair agreement with experiments. And finally, in addition to the 12 Standard Model bosons, there are 12 new force particles in SU(5), called *X* bosons.

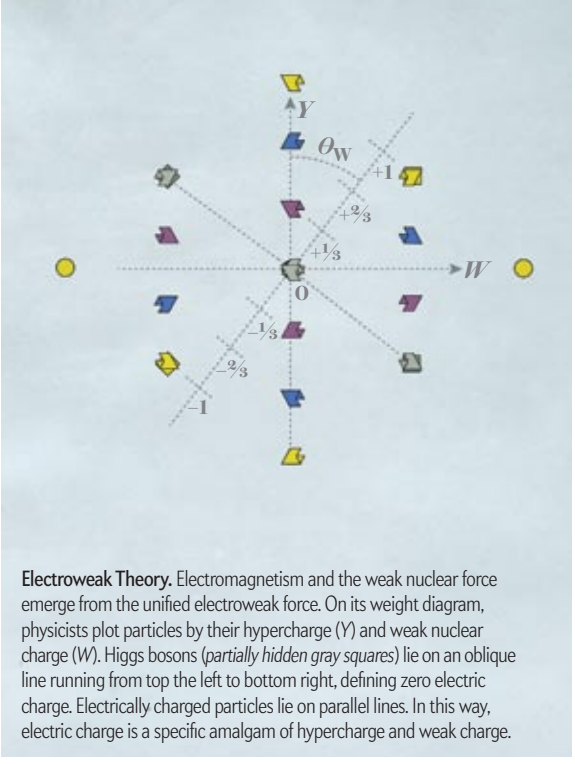
DIAGRAMS OF PARTICLE CHARGES

A Progression of Theories

Each type of elementary particle corresponds to a different fiber. These fibers twist around the various circular fibers of photons and other force particles; the twisting corresponds to their electric and other charges, which mathematicians call "weights." Each force of nature has its own type of charge and is mediated by its own force particles. The patterns of particles' charges describe the geometry of how the fibers twist around one another, governing how the corresponding particles can interact.

BOSONS	FERMIONS	
Photon	Neutrino	Left-handed spin-up
Weak bosons	Electron	Left-handed spin-down
Gluons	Up quark	Right-handed spin-up
Gravitons	Down quark	Right-handed spin-down
Frame-Higgs	Up quark	Right-handed spin-up anti
Weaker bosons	Down quark	Right-handed spin-down anti
X bosons	Up quark	Left-handed spin-up anti
More Higgs	Down quark	Left-handed spin-down anti

The world of elementary particles is a veritable menagerie. Particles come in two broad types, bosons (which transmit forces) and fermions (which constitute matter). Each fermion can come in several varieties: particle or antiparticle, left- or right-handed, spin up or down, and, for quarks, one of three colors. Every particle, identified by its charges, can be plotted in a weight diagram.



Electroweak Theory. Electromagnetism and the weak nuclear force emerge from the unified electroweak force. On its weight diagram, physicists plot particles by their hypercharge (*Y*) and weak nuclear charge (*W*). Higgs bosons (*partially hidden gray squares*) lie on an oblique line running from top the left to bottom right, defining zero electric charge. Electrically charged particles lie on parallel lines. In this way, electric charge is a specific amalgam of hypercharge and weak charge.

It was the *X* bosons that got the theory into trouble. These new particles would allow protons to decay into lighter particles, which they cannot do in the Standard Model. In impressive experiments, including the observation of 50,000 tons of water in a converted Japanese mine, the predicted proton decay was not seen. Thus, physicists have ruled out this theory.

Despite the SU(5) theory's failures, its successes suggest that theorists are generally on the right track. A related Grand Unified Theory, developed around the same time, is based on the Lie group Spin(10). It produces the same hypercharges and weak mixing angle as SU(5) and also predicts the existence of a new force, very similar to the weak force. This new "weaker" force, mediated by relatives of the weak-force bosons called W'^{+}, W'^{-} and W'^{3}, interacts with right-handed fermions, restoring left-right symmetry to the universe at short distances. Although this theory predicts an abundance of *X* bosons—a full 30 of them—it also indicates that proton decay would occur at a lower rate than for the SU(5) theory. So the theory remains viable.

Drawn a certain way, the weight diagram for the Spin(10) GUT shows that particle charges align in four concentric circles—an unusually pretty pattern [*see left panel on next page*]. The balance evident in this diagram arises for a deep reason: the Spin(10) Lie group with its 45 bosons, along with its representations of 16 fermions and their 16 antifermions, are in fact all parts of a single Lie group, a special one known as the exceptional Lie group E6.

The exceptional groups play an exalted role in mathematics. Because there are only so many ways circles can twist around one another, there are only a handful of different kinds of Lie groups. Mathematicians completed their classification a century ago. We have already met two, SU and Spin, encountered quite often in physics. And among the Lie groups there are five exceptional cases that stand out: G2, F4, E6, E7 and E8. These Lie groups have especially intricate structures and deep connections to many areas of mathematics.

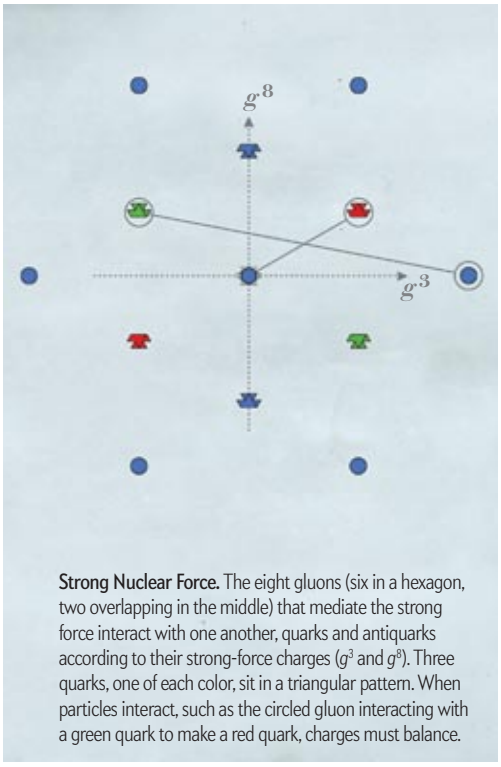
The fact that the bosons and fermions of Spin(10) and the Standard Model tightly fit the structure of E6, with its 78 generators, is remarkable. It provokes a radical thought. Up until now, physicists have thought of bosons and fermions as completely different. Bosons are parts of Lie group force fibers, and fermions are different kinds of fibers, twisting around the Lie groups. But what if bosons and fermions are parts of a single fiber? That is what the embedding of the Spin(10) GUT in E6 suggests. The structure of E6 includes both types of particles. In a radical unification of forces and matter, bosons and fermions can be combined as parts of a superconnection field.

Although several people have criticized this idea because it combines fermions and bosons in a way that at first appears fundamentally inconsistent, it relies on solid mathematics. And the curvature of this superconnection, describing the twisting of E6 over spacetime, succinctly describes the dynamics and interactions of bosons and fermions in the Standard Model. But E6 does not include the Higgs bosons or gravity.

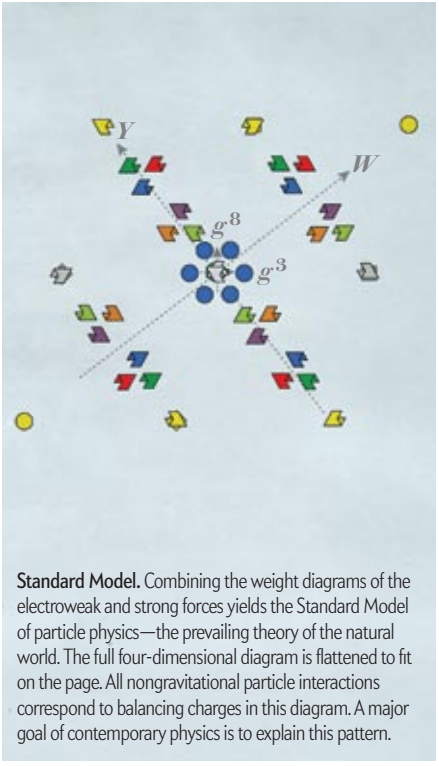
TAKING GRAVITY FOR A SPIN

ALBERT EINSTEIN originally described gravity as the curvature of spacetime. His mathematical machinery was state-of-the-art at the time, but researchers have gradually adopted a more modern, equivalent description of gravity based on a fiber bundle.

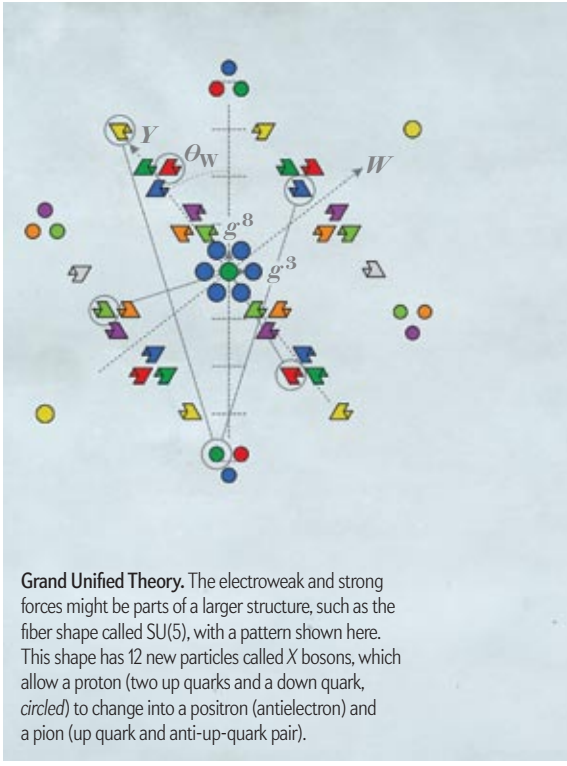
At every spacetime point, we can imagine three perpendicular rulers and a clock, called a frame of reference. Without the frame, spacetime would not be "spacetime" but just a four-dimensional



Strong Nuclear Force. The eight gluons (six in a hexagon, two overlapping in the middle) that mediate the strong force interact with one another, quarks and antiquarks according to their strong-force charges (g^3 and g^8). Three quarks, one of each color, sit in a triangular pattern. When particles interact, such as the circled gluon interacting with a green quark to make a red quark, charges must balance.



Standard Model. Combining the weight diagrams of the electroweak and strong forces yields the Standard Model of particle physics—the prevailing theory of the natural world. The full four-dimensional diagram is flattened to fit on the page. All nongravitational particle interactions correspond to balancing charges in this diagram. A major goal of contemporary physics is to explain this pattern.



Grand Unified Theory. The electroweak and strong forces might be parts of a larger structure, such as the fiber shape called SU(5), with a pattern shown here. This shape has 12 new particles called *X* bosons, which allow a proton (two up quarks and a down quark, *circled*) to change into a positron (antielectron) and a pion (up quark and anti-up-quark pair).

fabric with no sense of orientation or distance. As we move to different points in spacetime, there are different sets of rulers and clocks, related to our original frame by a rotation. This rotation can be an ordinary rotation in space or, because Einstein showed that space and time are unified, a rotation of space into time. How the frame rotates from point to point is determined by the spin connection, more commonly known as the gravitational field. The Lie group of possible rotations in three spaces and one time direction is Spin(1,3)—the Lie group of gravity. We feel the force of gravity because the gravitational spin connection field is rotating our frame as we move through time, attempting to steer us toward Earth's center.

Just as particles have different kinds of charge describing how they interact with Standard Model forces, they have a type of charge describing how they behave within space. Consider what happens if we rotate a ruler in space by 360 degrees: it returns to its original state. This ruler—and the gravitational frame field—has spatial spin charge of +1 or –1. But if we rotate a fermion, such as an electron, in space by 360 degrees, it does not return to the same state it started in. To return it to its original state, we have to rotate it by 720 degrees. The fermion has spin charge of ±½.

Spin charge plays a role in gravity because gravity, through the frame and spin connection, is related to the geometry of spacetime. As we did for the other forces, we can make a weight diagram for gravity based on spin [*see center panel below*]. A particle's spatial spin charge is its internal angular momentum, and its temporal spin charge is related to its motion through space. Fermions whose spatial spin and motion align, plotted in the upper right or lower left of the diagram, make a right-handed corkscrew as they travel through space. Fermions with opposite motion and spatial spin are left-handed.

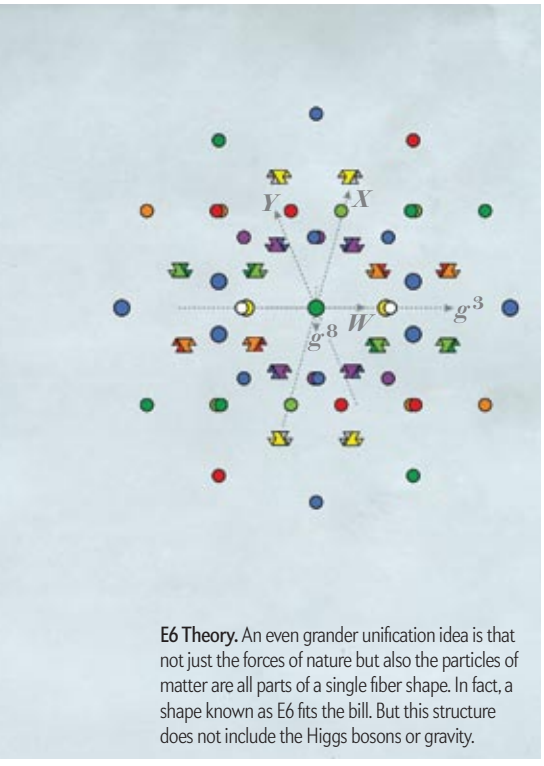
What is strange is that spin charge also has an unexpected relevance to the weak nuclear force. Only left-handed particles and right-handed antiparticles have weak charge and interact with the weak force. The fact that the weak force is sensitive to spin charge suggests that gravity and the other forces, though outwardly dissimilar, in fact have a deep relationship.

E PLURIBUS UNUM

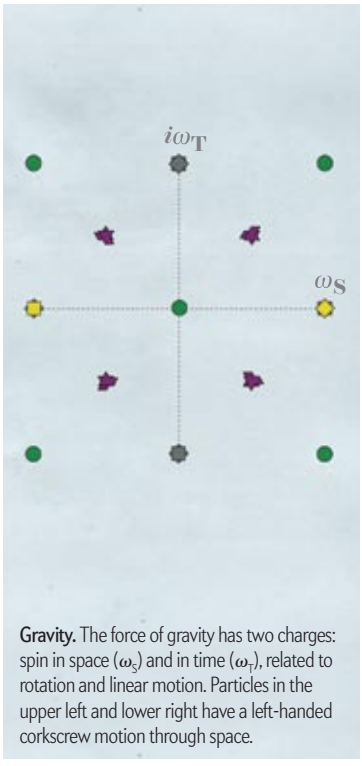
NOW IT IS JUST A MATTER of putting the pieces together. With gravity described by Spin(1,3) and the favored Grand Unified Theory based on Spin(10), it is natural to combine them using a single Lie group, Spin(11,3), yielding a Gravitational Grand Unified Theory—as introduced last year by Roberto Percacci of the International School for Advanced Studies in Trieste and Fabrizio Nesti of the University of Ferrara in Italy. It brings us close to a full Theory of Everything.

The Spin(11,3) Lie group allows for blocks of 64 fermions and, amazingly, predicts their spin, electroweak and strong charges perfectly. It also automatically includes a set of Higgs bosons and the gravitational frame; in fact, they are unified as "frame-Higgs" generators in Spin(11,3). The curvature of the Spin(11,3) fiber bundle correctly describes the dynamics of gravity, the other forces and the Higgs. It even includes a cosmological constant that explains cosmic dark energy. Everything falls into place.

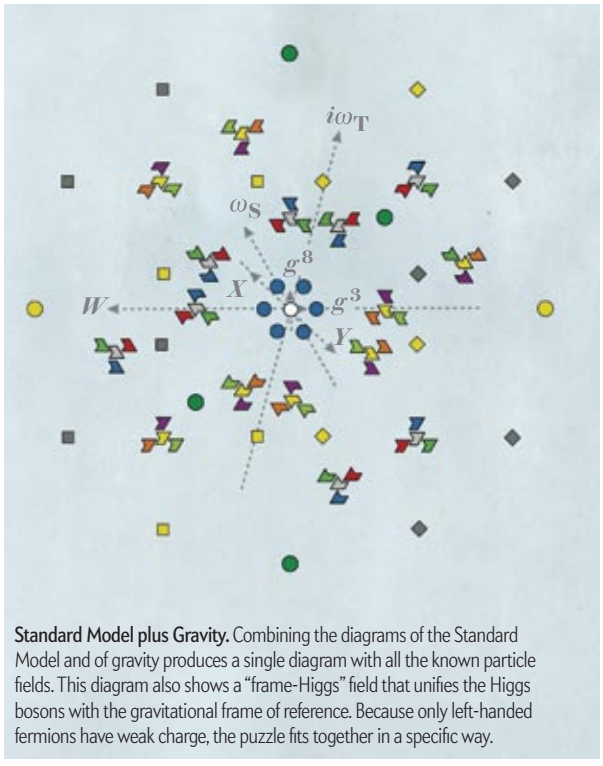
Skeptics objected that such a theory should be impossible. It appears to violate a theorem in particle physics, the Coleman-Mandula theorem, which forbids combining gravity with the other forces in a single Lie group. But the theorem has an important loophole: it applies only when spacetime exists. In the Spin(11,3) theory (and in E8 theory), gravity is unified with the other forces only before the full Lie group symmetry is broken, and when that



E6 Theory. An even grander unification idea is that not just the forces of nature but also the particles of matter are all parts of a single fiber shape. In fact, a shape known as E6 fits the bill. But this structure does not include the Higgs bosons or gravity.



Gravity. The force of gravity has two charges: spin in space (ω_S) and in time (ω_T), related to rotation and linear motion. Particles in the upper left and lower right have a left-handed corkscrew motion through space.



Standard Model plus Gravity. Combining the diagrams of the Standard Model and of gravity produces a single diagram with all the known particle fields. This diagram also shows a "frame-Higgs" field that unifies the Higgs bosons with the gravitational frame of reference. Because only left-handed fermions have weak charge, the puzzle fits together in a specific way.

is true, spacetime does not yet exist. Our universe begins when the symmetry breaks: the frame-Higgs field becomes nonzero, singling out a specific direction in the unifying Lie group. At this instant, gravity becomes an independent force, and spacetime comes into existence with a bang. Thus, the theorem is always satisfied. The dawn of time was the breaking of perfect symmetry.

The weight diagram of the Spin(11,3) theory is finely patterned and balanced. Its symmetry, like that of the Spin(10) GUT, hints at deeper, exceptional mathematics. This elegant pattern of particles is part of what is perhaps the most beautiful structure in all of mathematics, the largest simple exceptional Lie group, E8. Just as E6 contains the structure of the Spin(10) Grand Unified Theory, with its 16 fermions, the E8 Lie group contains the structure of the Spin(11,3) Gravitational Grand Unified Theory, with its 64 Standard Model fermions, including their spins. In this way, gravity and the other known forces, the Higgs, and one generation of Standard Model fermions are all parts of the unified superconnection field of an E8 fiber bundle.

The E8 Lie group, with 248 generators, has a wonderfully intricate structure. In addition to gravity and the Standard Model particles, E8 includes W', Z' and X bosons, a rich set of Higgs bosons, novel particles called mirror fermions, and axions—a cosmic dark matter candidate. Even more intriguing is a symmetry of E8 called triality. Using triality, the 64 generators of one generation of Standard Model fermions can be related to two other blocks of 64 generators. These three blocks might intermix to reproduce the three generations of known fermions.

COLLIDING WITH REALITY

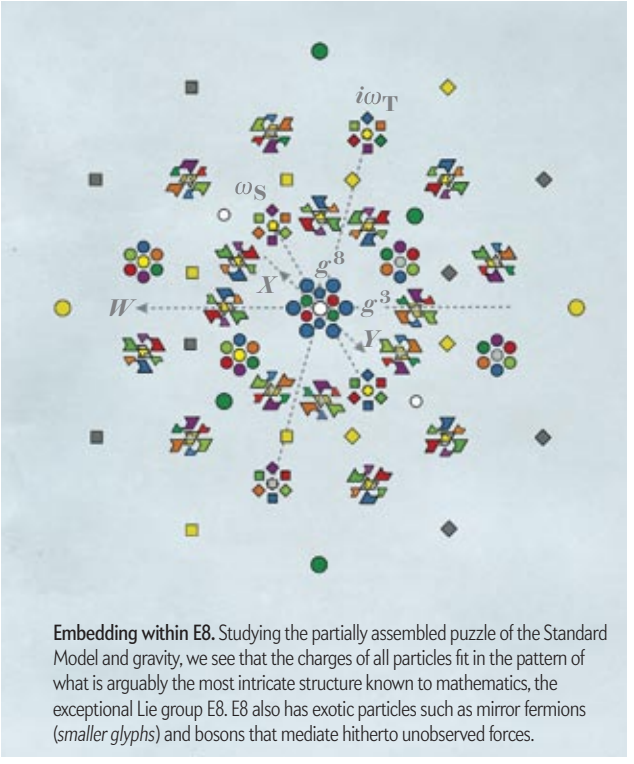
IN THIS WAY, the physical universe could emerge naturally from a mathematical structure without peer. The theory tells us what Higgs bosons are, how gravity and the other forces emerge from symmetry-breaking, why fermions exist with the spins and charges they have, and why all these particles interact as they do. In July those of us studying the theory held an exciting and productive workshop in Banff in Alberta, Canada, and we are planning a follow-up. Although this new theory continues to be promising, much work remains to be done. We need to figure out how three generations of fermions unfold, how they mix and interact with the Higgs to get their masses, and exactly how E8 theory works within the context of quantum theory.

If E8 theory is correct, it is likely the Large Hadron Collider will detect some of its predicted particles. If, on the other hand, the collider detects new particles that do not fit E8's pattern, that could be a fatal blow for the theory. In either case, any particles that experimentalists uncover will take their place in a weight diagram, leading us toward some geometric structure at the heart of nature. And if the structure of the universe at the tiny scales of elementary particles does turn out to be described by E8, with its 248 sets of circles wrapping around one another in an exquisite pattern, twisting and dancing over spacetime in all possible ways, then we will have achieved a complete unification and have the satisfaction of knowing we live in an exceptionally beautiful universe. SA

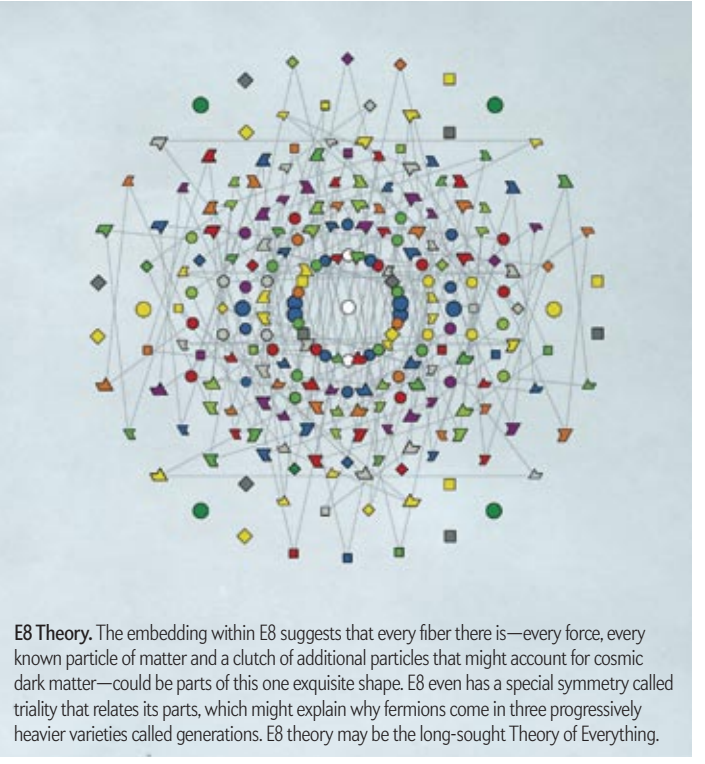
MORE TO EXPLORE

Deep Down Things. Bruce A. Schumm. Johns Hopkins University Press, 2004.
Lie Groups, Physics, and Geometry. Robert Gilmore. Cambridge University Press, 2008.
The Beauty of Particle Physics. A. Garrett Lisi. **www.ted.com/index.php/talks/garrett_lisi_on_his_theory_of_everything.html**
An Exceptionally Simple Theory of Everything. A. Garrett Lisi. **http://arxiv.org/abs/0711.0770**

TO EXPLORE THE STANDARD MODEL and proposed extensions such as E8 theory, visit the Elementary Particle Explorer at **http://deferentialgeometry.org/epe**



Embedding within E8. Studying the partially assembled puzzle of the Standard Model and gravity, we see that the charges of all particles fit in the pattern of what is arguably the most intricate structure known to mathematics, the exceptional Lie group E8. E8 also has exotic particles such as mirror fermions (*smaller glyphs*) and bosons that mediate hitherto unobserved forces.



E8 Theory. The embedding within E8 suggests that every fiber there is—every force, every known particle of matter and a clutch of additional particles that might account for cosmic dark matter—could be parts of this one exquisite shape. E8 even has a special symmetry called triality that relates its parts, which might explain why fermions come in three progressively heavier varieties called generations. E8 theory may be the long-sought Theory of Everything.

PALEONTOLOGY

BLOOD FROM STONE

Mounting evidence from dinosaur bones shows that, contrary to common belief, organic materials can sometimes survive in fossils for millions of years

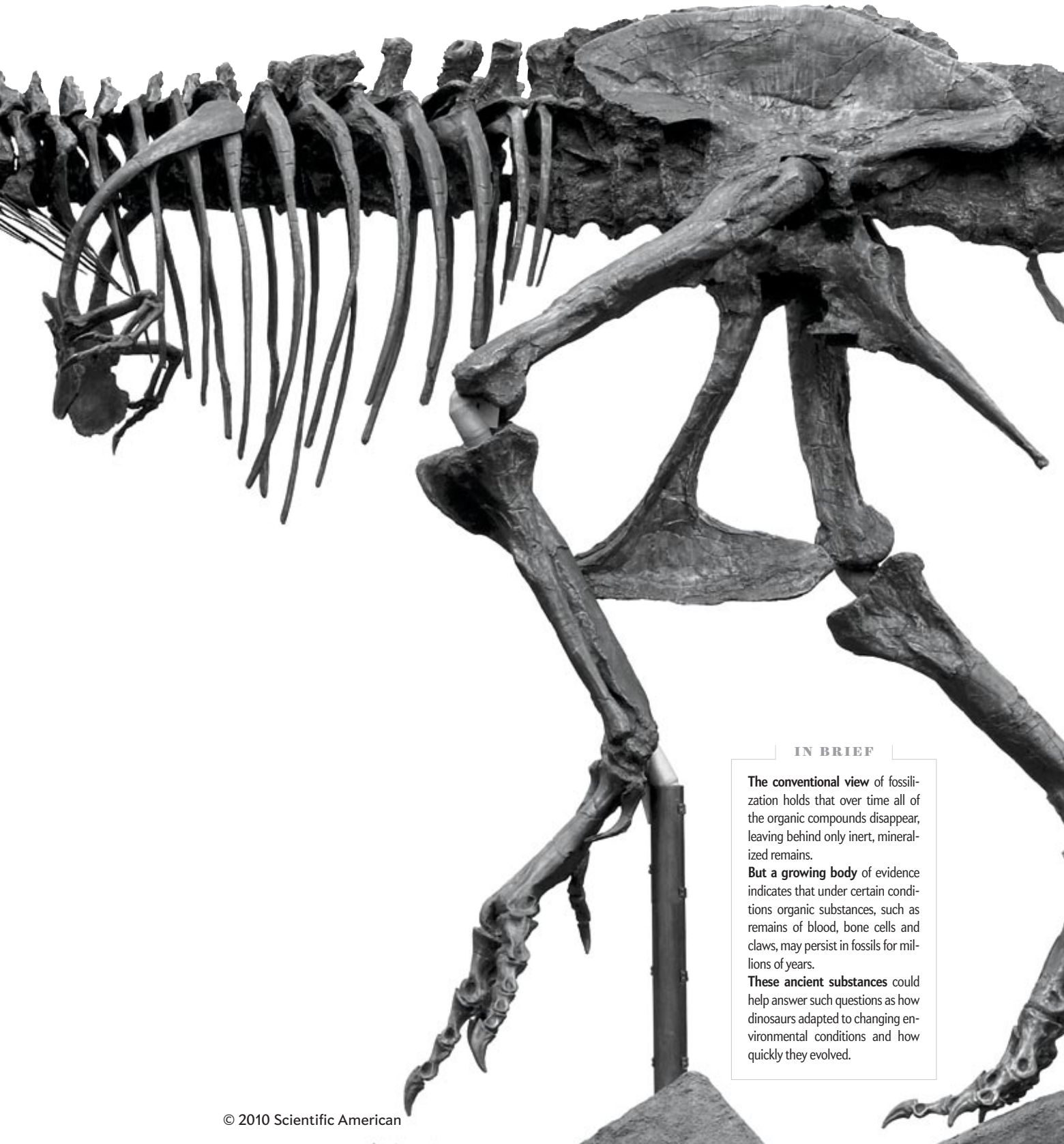
By Mary H. Schweitzer

PEERING THROUGH THE MICROSCOPE AT THE THIN SLICE OF fossilized bone, I stared in disbelief at the small red spheres a colleague had just pointed out to me. The tiny structures lay in a blood vessel channel that wound through the pale yellow hard tissue. Each had a dark center resembling a cell nucleus. In fact, the spheres looked just like the blood cells in reptiles, birds and all other vertebrates alive today except mammals, whose circulating blood cells lack a nucleus. They couldn't be cells, I told myself. The bone slice was from a dinosaur that a team from the Museum of the Rockies in Bozeman, Mont., had recently uncovered—a *Tyrannosaurus rex* that died some 67 million years ago—and everyone knew organic material was far too delicate to persist for such a vast stretch of time.

Tyrannosaurus rex **known as MOR 555, or "Big Mike," a replica of which is shown here, is one of several dinosaurs whose bones have yielded organic matter.**

Photograph by David Liittschwager

Mary H. Schweitzer had already trained to become a high school science teacher when she took a class in paleontology for fun and reignited a childhood interest in dinosaurs. She then earned a Ph.D. in biology from Montana State University in 1995. Today she is an associate professor in the department of marine, earth and atmospheric sciences at North Carolina State University and an associate curator at the North Carolina Museum of Natural Sciences.



IN BRIEF

The conventional view of fossilization holds that over time all of the organic compounds disappear, leaving behind only inert, mineralized remains.

But a growing body of evidence indicates that under certain conditions organic substances, such as remains of blood, bone cells and claws, may persist in fossils for millions of years.

These ancient substances could help answer such questions as how dinosaurs adapted to changing environmental conditions and how quickly they evolved.

For more than 300 years paleontologists have operated under the assumption that the information contained in fossilized bones lies strictly in the size and shape of the bones themselves. The conventional wisdom holds that when an animal dies under conditions suitable for fossilization, inert minerals from the surrounding environment eventually replace all of the organic molecules—such as those that make up cells, tissues, pigments and proteins—leaving behind bones composed entirely of mineral. As I sat in the museum that afternoon in 1992, staring at the crimson structures in the dinosaur bone, I was actually looking at a sign that this bedrock tenet of paleontology might not always be true—though at the time, I was mostly puzzled. Given that dinosaurs were nonmammalian vertebrates, they would have had nucleated blood cells, and the red items certainly looked the part, but so, too, they could have arisen from some geologic process unfamiliar to me.

Back then, I was a relatively new graduate student at Montana State University, studying the microstructure of dinosaur bone, hardly a seasoned pro. After I sought opinions on the identity of the red spheres from faculty members and other graduate students, word of the puzzle reached Jack Horner, curator of paleontology at the museum and one of the world's foremost dinosaur authorities. He took a look for himself. Brows furrowed, he gazed through the microscope for what seemed like hours without saying a word. Then, looking up at me with a frown, he asked, "What do *you* think they are?" I replied that I did not know, but they were the right size, shape and color to be blood cells, and they were in the right place, too. He grunted. "So prove to me they aren't." It was an irresistible challenge, and one that has helped frame how I ask my research questions, even now.

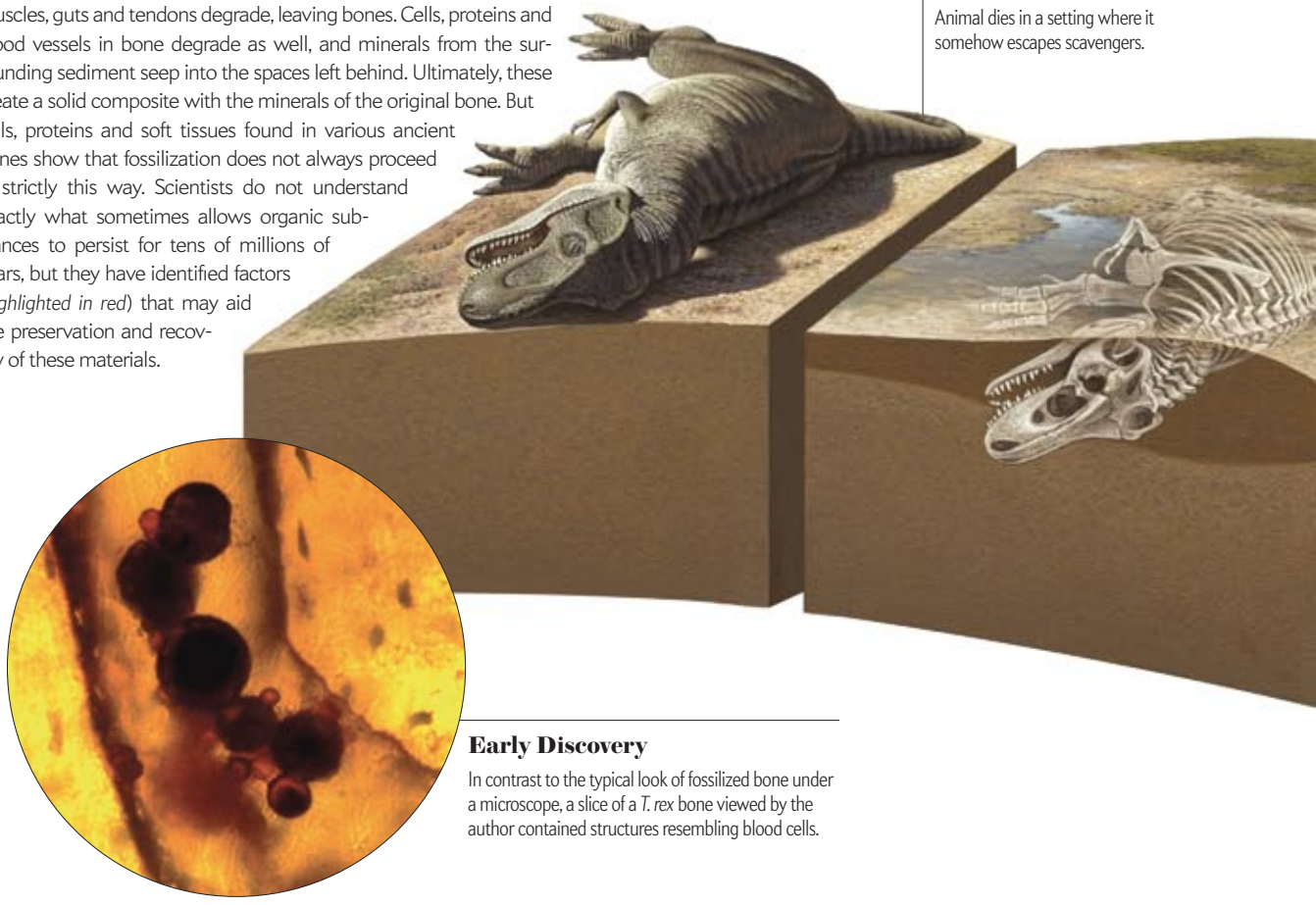
Since then, my colleagues and I have recovered various types of organic remains—including blood vessels, bone cells and bits of the fingernail-like material that makes up claws—from multiple specimens, indicating that although soft-tissue preservation in fossils may not be common, neither is it a one-time occurrence. These findings not only diverge from textbook description of the fossilization process, they are also yielding fresh in-

COURTESY OF MARY H. SCHWEITZER (*micrograph*)

HOW FOSSILIZATION OCCURS

The Textbook Story, with a Twist

In the classic picture of how an animal becomes fossilized, the skin, muscles, guts and tendons degrade, leaving bones. Cells, proteins and blood vessels in bone degrade as well, and minerals from the surrounding sediment seep into the spaces left behind. Ultimately, these create a solid composite with the minerals of the original bone. But cells, proteins and soft tissues found in various ancient bones show that fossilization does not always proceed in strictly this way. Scientists do not understand exactly what sometimes allows organic substances to persist for tens of millions of years, but they have identified factors (*highlighted in red*) that may aid the preservation and recovery of these materials.



Death

Animal dies in a setting where it somehow escapes scavengers.

Early Discovery

In contrast to the typical look of fossilized bone under a microscope, a slice of a *T. rex* bone viewed by the author contained structures resembling blood cells.

Illustration by Raúl Martin

sights into the biology of bygone creatures. For instance, bone from another *T. rex* specimen has revealed that the animal was a female that was "in lay" (preparing to lay eggs) when she died—information we could not have gleaned from the shape and size of the bones alone. And a protein detected in remnants of fibers near a small carnivorous dinosaur unearthed in Mongolia has helped establish that the dinosaur had feathers that, at the molecular level, resembled those of birds.

Our results have met with a lot of skepticism—they are, after all, extremely surprising. But the skepticism is a proper part of science, and I continue to find the work fascinating and full of promise. The study of ancient organic molecules from dinosaurs has the potential to advance understanding of the evolution and extinction of these magnificent creatures in ways we could not have imagined just two decades ago.

FIRST SIGNS

EXTRAORDINARY CLAIMS, as the old adage goes, require extraordinary evidence. Careful scientists make every effort to disprove cherished hypotheses before they accept that their ideas are correct. Thus, for the past 20 years I have been trying every experiment I can think of to disprove the hypothesis that the materials my collaborators and I have discovered are components of soft tissues from dinosaurs and other long-gone animals.

In the case of the red microstructures I saw in the *T. rex* bone, I started by thinking that if they were related to blood cells or to blood cell constituents (such as molecules of hemoglobin or heme that had clumped together after being released from dying blood cells), they would have persisted in some, albeit possibly very altered, form only if the bones themselves were exceptionally well preserved. Such tissue would have disappeared in poorly preserved skeletons. At the macroscopic level, this was clearly true. The skeleton, a nearly complete specimen from eastern Montana—officially named MOR 555 and affectionately dubbed "Big Mike"—includes many rarely preserved bones. Microscope examination of thin sections of the limb bones revealed similarly pristine preservation. Most of the blood vessel channels in the dense bone were empty, not filled with mineral

Burial

Carcass is covered with sediment before scavengers or weathering obliterates it, such as may happen when a river with a heavy sediment load washes over a floodplain.

Sandstone sediments in particular seem to protect against complete loss of organic remains, possibly because the porous sands allow the corrosive fluids that form during decomposition to drain away.

Deeper Burial

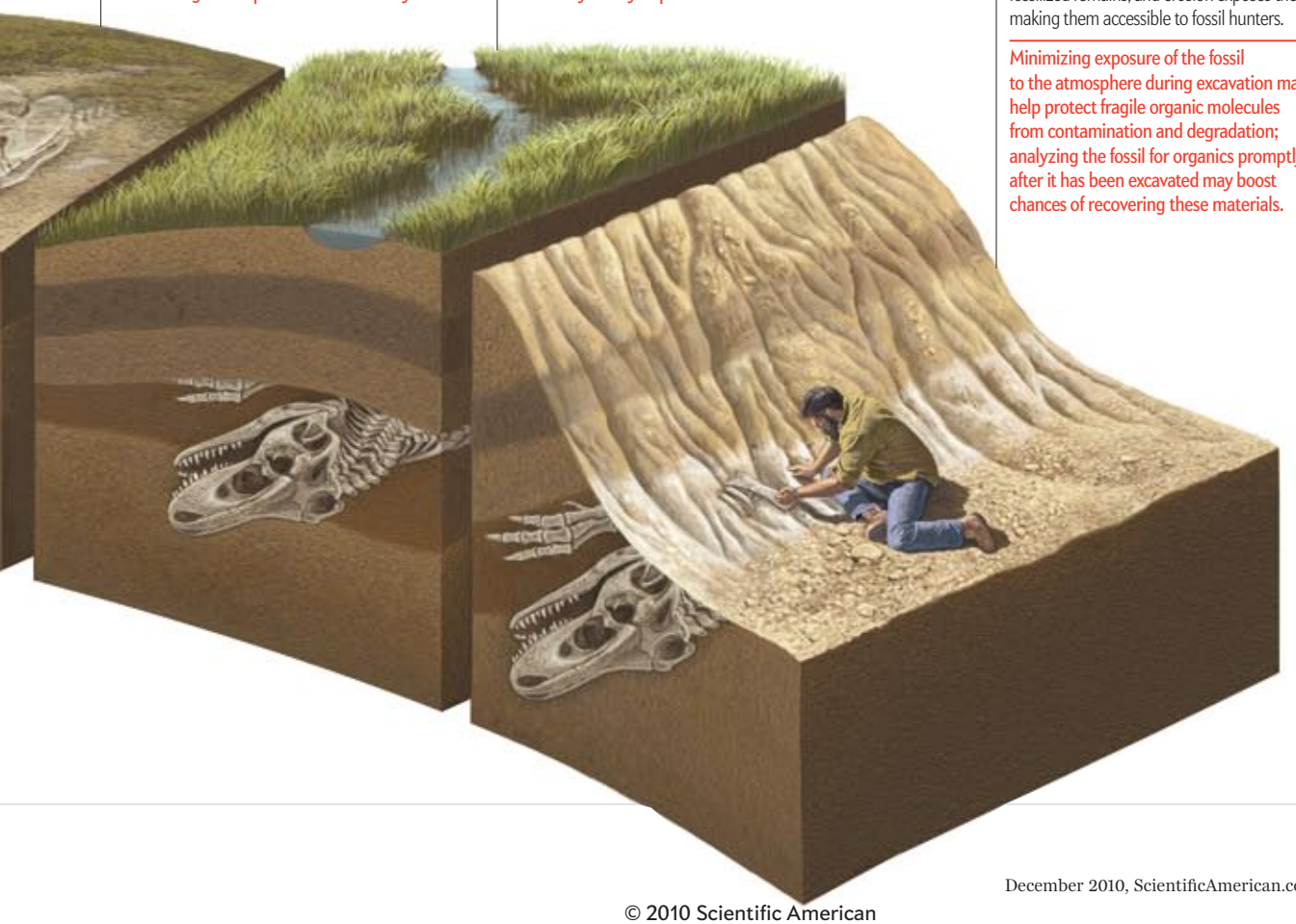
Repeated deposition of sediments over millions of years buries the carcass far below the surface, where minerals from groundwater filter into the bones.

Especially deep burial may promote soft-tissue preservation because it protects against oxidation, changes in pH and temperature, and exposure to ultraviolet radiation that can occur at the surface. Eventually the animal comes into chemical equilibrium with the underground environment, which may be key to preservation.

Exposure

Movements of the earth's crust uplift the sedimentary layers that contain the fossilized remains, and erosion exposes them, making them accessible to fossil hunters.

Minimizing exposure of the fossil to the atmosphere during excavation may help protect fragile organic molecules from contamination and degradation; analyzing the fossil for organics promptly after it has been excavated may boost chances of recovering these materials.



deposits as is usually the case with dinosaurs. And those ruby microscopic structures appeared only in the vessel channels, never in the surrounding bone or in sediments adjacent to the bones, just as should be true of blood cells.

Next, I turned my attention to the chemical composition of the blood cell look-alikes. Analyses showed that they were rich in iron, as red blood cells are, and that the iron was specific to them. Not only did the elemental makeup of the mysterious red things (we nicknamed them LLRTs, "little round red things") differ from that of the bone immediately surrounding the vessel channels, it was also utterly distinct from that of the sediments in which the dinosaur was buried. But to further test the connection between the red structures and blood cells, I wanted to examine my samples for heme, the small iron-containing molecule that gives vertebrate blood its scarlet hue and enables hemoglobin proteins to carry oxygen from the lungs to the rest of the body. Heme vibrates, or resonates, in telltale patterns when it is stimulated by tuned lasers, and because it contains a metal center, it absorbs light in a very distinct way. When we subjected bone samples to spectroscopy tests—which measure the light that a given material emits, absorbs or scatters—our results showed that somewhere in the dinosaur's bone were compounds that were consistent with heme.

Through the *T. rex* work, I began to realize just how much fossil organics stood to reveal about extinct animals.

One of the most compelling experiments we conducted took advantage of the immune response. When the body detects an invasion by foreign, potentially harmful substances, it produces defensive proteins called antibodies that can specifically recognize, or bind to, those substances. We injected extracts of the dinosaur bone into mice, causing the mice to make antibodies against the organic compounds in the extract. When we then exposed these antibodies to hemoglobin from turkeys and rats, they bound to the hemoglobin—a sign that the extracts that elicited antibody production in the mice had included hemoglobin or something very like it. The antibody data supported the idea that Big Mike's bones contained something similar to the hemoglobin in living animals.

None of the many chemical and immunological tests we performed disproved our hypothesis that the mysterious red structures visible under the microscope were red blood cells from a *T. rex*. Yet we could not show that the hemoglobinlike substance was specific to the red structures—the available techniques were not sufficiently sensitive to permit such differentiation. Thus, we could not claim definitively that they were blood cells. When we published our findings in 1997, we drew our conclusions conservatively, stating that hemoglobin proteins might be preserved and that the most likely source of such proteins was the cells of the dinosaur. The paper got very little notice.

THE EVIDENCE BUILDS

THROUGH THE *T. REX* WORK, I began to realize just how much fossil organics stood to reveal about extinct animals. If we could obtain proteins, we could conceivably decipher the sequence of their constituent amino acids, much as geneticists sequence the "letters" that make up DNA. And like DNA sequences, protein sequences contain information about evolutionary relationships between animals, how species change over time and how the acquisition of new genetic traits might have conferred advantages to the animals possessing those features. But first I had to show that ancient proteins were present in fossils other than the wonderful *T. rex* we had been studying. Working with Mark Marshall, then at Indiana University, and with Seth Pincus and John Watt, both at Montana State during this time, I turned my attention to two well-preserved fossils that looked promising for recovering organics.

The first was a beautiful primitive bird named *Rahonavis* that paleontologists from Stony Brook University and Macalester College had unearthed from deposits in Madagascar dating to the Late Cretaceous period, around 80 million to 70 million years ago. During excavation they had noticed a white, fibrous material on the skeleton's toe bones. No other bone in the quarry seemed to have the substance, nor was it present on any of the sediments there, suggesting that it was part of the animal rather than having been deposited on the bones secondarily. They wondered whether the material might be akin to the strong sheath made of keratin protein that covers the toe bones of living birds, forming their claws, and asked for my assistance.

Keratin proteins are good candidates for preservation because they are abundant in vertebrates, and the composition of this protein family makes them very resistant to degradation—something that is nice to have in organs such as skin that are exposed to harsh conditions. They come in two main types: alpha and beta. All vertebrates have alpha keratin, which in humans makes up hair and nails and helps the skin to resist abrasion and dehydration. Beta keratin is absent from mammals and occurs only in birds and reptiles among living organisms.

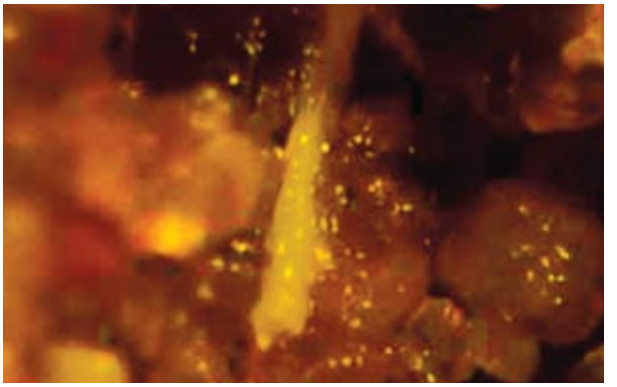
To test for keratins in the white material on the *Rahonavis* toe bones, we employed many of the same techniques I had used to study *T. rex*. Notably, antibody tests indicated the presence of both alpha and beta keratin. We also applied additional diagnostic tools. Other analyses, for instance, detected amino acids that were localized to the toe-bone covering and also detected nitrogen (a component of amino acids) that was bound to other compounds much as proteins bind together in living tissues, including in keratin. The results of all our tests supported the notion that the cryptic white material covering the ancient bird's toe bones included fragments of alpha and beta keratin and was the remainder of its once lethal claws.

The second specimen we probed was a spectacular Late Cretaceous fossil that researchers from the American Museum of Natural History in New York City had discovered in Mongolia. Although the scientists dubbed the animal *Shuvuuia deserti,* or "desert bird," it was actually a small carnivorous dinosaur. While cleaning the fossil, Amy Davidson, a technician at the museum, noticed small white fibers in the animal's neck region. She asked me if I could tell if they were remnants of feathers. Birds are descended from dinosaurs, and fossil hunters have discovered a number of dinosaur fossils that preserve impressions of feathers, so in theory the suggestion that *Shuvuuia* had a downy coat was plausible. I did not expect that a structure as delicate as a feather could have endured the ravages of time, however. I suspected the white fibers instead came from modern plants or from fungi. But I agreed to take a closer look.

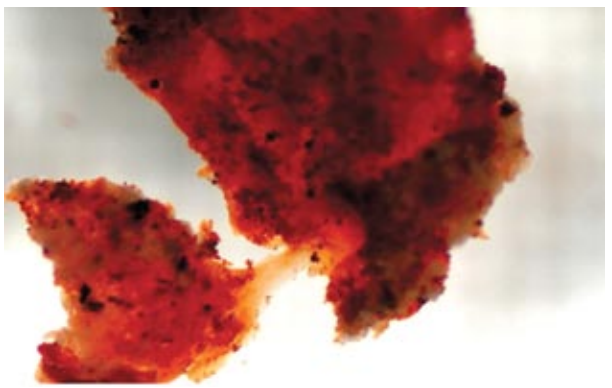
Ancient Organic Remains

Researchers have now recovered soft tissues from multiple fossils dating back tens of millions of years.

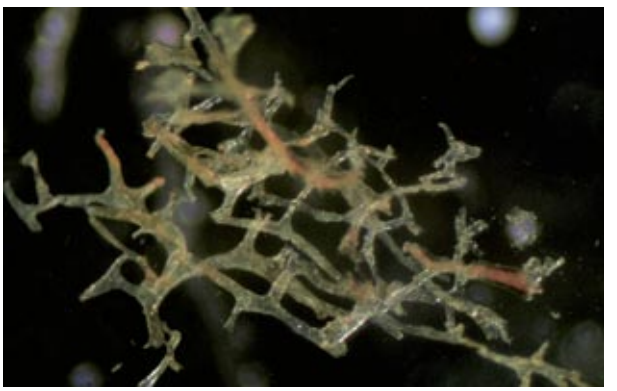
Toe bone of a bird called *Rahonavis ostromi,* which lived roughly 80 million to 70 million years ago in Madagascar, bears a white material that seems to be a remnant of the protein sheathing that covered the creature's claws.



Hollow filament (*center*) resembling a feather fiber belonged to a small carnivorous dinosaur known as *Shuvuuia deserti* that inhabited Mongolia 83 million to 70 million years ago.



Medullary bone—a special tissue that appears for a limited time when a female's body readies eggs for laying—was found in a 68-million-year-old bone from a *T. rex* discovered in Montana.



Blood vessels—or their look-alikes—emerged when minerals were dissolved away from pieces of a common kind of bone, called cortical bone, in the Montana *T. rex*.

COURTESY OF MARYLOU STEWART *Stony Brook University (toe bone);* COURTESY OF MARY H. SCHWEITZER *(hollow filament and blood vessels);* FROM "SOFT-TISSUE VESSELS AND CELLULAR PRESERVATION IN *TYRANNOSAURUS REX*," BY MARY H. SCHWEITZER ET AL., IN *SCIENCE*, VOL. 307; MARCH 25, 2005 *(collagen)*

To my surprise, initial tests ruled out plants or fungi as the source of the fibers. Moreover, subsequent analyses of the microstructure of the strange white strands pointed to the presence of keratin. Mature feathers in living birds consist almost exclusively of beta keratin. If the small fibers on *Shuvuuia* were related to feathers, then they should harbor beta keratin alone, in contrast to the claw sheath of *Rahonavis,* which contained both alpha and beta keratin. That, in fact, is exactly what we found when we conducted our antibody tests—results we published in 1999.

EXTRAORDINARY FINDS

BY NOW I WAS CONVINCED that small remnants of original proteins could survive in extremely well preserved fossils and that we had the tools to identify them. But many in the scientific community remained unconvinced. Our findings challenged everything scientists thought they knew about the breakdown of cells and molecules. Test-tube studies of organic molecules indicated that proteins should not persist more than a million years or so; DNA had an even shorter life span. Researchers working on ancient DNA had claimed previously that they had recovered DNA millions of years old, but subsequent work failed to validate the results. The only widely accepted claims of ancient molecules were no more than several tens of thousands of years old. In fact, one anonymous reviewer of a paper I had submitted for publication in a scientific journal told me that this type of preservation was not possible and that I could not convince him or her otherwise, regardless of our data.

In response to this resistance, a colleague advised me to step back a bit and demonstrate the efficacy of our methods for identifying ancient proteins in bones that were old, but not as old as dinosaur bone, to provide a proof of principle. Working with analytical chemist John Asara of Harvard University, I obtained proteins from mammoth fossils that were estimated to be 300,000 to 600,000 years old. Sequencing of the proteins using a technique called mass spectrometry identified them unambiguously as collagen, a key component of bone, tendons, skin and other tissues. The publication of our mammoth results in 2002

did not trigger much controversy. Indeed, the scientific community largely ignored it. But our proof of principle was about to come in very handy.

The next year a crew from the Museum of the Rockies finally finished excavating another *T. rex* skeleton, which at 68 million years old is the oldest one to date. Like the younger *T. rex,* this one—called MOR 1125 and nicknamed "Brex," after discoverer Bob Harmon—was recovered from the Hell Creek Formation in eastern Montana. The site is isolated and remote, with no access for vehicles, so a helicopter ferried plaster jackets containing excavated bones from the site to the camp. The jacket containing the leg bones was too heavy for the helicopter to lift. To retrieve them, then, the team broke the jacket, separated the bones and rejacketed them. But the bones are very fragile, and when the original jacket was opened, many fragments of bone fell out. These were boxed up for me. Because my original *T. rex* studies were controversial, I was eager to repeat the work on a second *T. rex.* The new find presented the perfect opportunity.

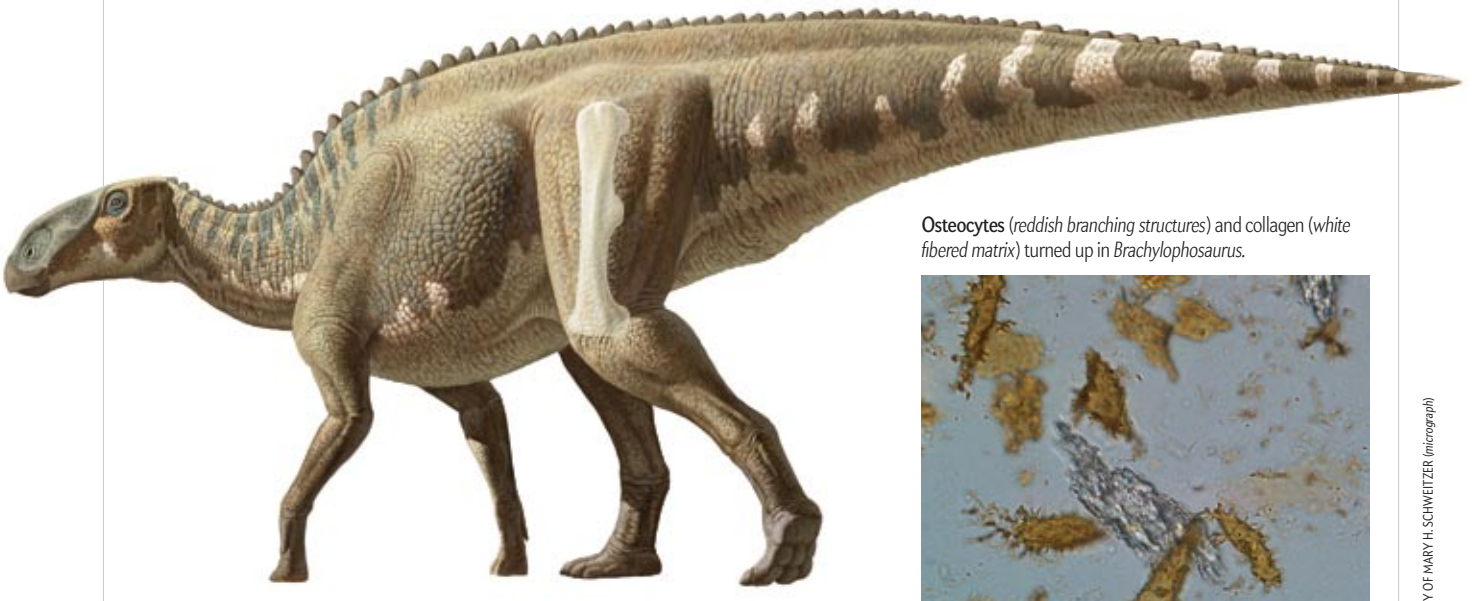
As soon as I laid eyes on the first piece of bone I removed from that box, a fragment of thighbone, I knew the skeleton was special. Lining the internal surface of this fragment was a thin, distinct layer of a type of bone that had never been found in dinosaurs. This layer was very fibrous, filled with blood vessel channels, and completely different in color and texture from the cortical bone that constitutes most of the skeleton. "Oh, my gosh, it's a girl—and it's pregnant!" I exclaimed to my assistant, Jennifer Wittmeyer. She looked at me like I had lost my mind. But having studied bird physiology, I was nearly sure that this distinctive feature was medullary bone, a special tissue that appears for only a limited time (often for just about two weeks), when birds are in lay, and that exists to provide an easy source of calcium to fortify the eggshells.

One of the characteristics that sets medullary bone apart from other bone types is the random orientation of its collagen fibers, a characteristic that indicates very rapid formation. (This same organization occurs in the first bone laid down when you have a fracture—that is why you feel a lump in healing bone.) The bones of a modern-day bird and all other animals can be demineralized using mild acids to reveal the telltale arrangement of the collagen fibers. Wittmeyer and I decided to try to remove the minerals. If this was medullary bone and if collagen was present, eliminating the minerals should leave behind randomly oriented fibers. As the minerals were removed, they left a flexible and fibrous clump of tissue. I could not believe what we were seeing. I asked Wittmeyer to repeat the experiment multiple times. And each time we placed the distinctive layer of bone in the mild acid solution, fibrous stretchy material remained—just as it does when medullary bone in birds is treated in the same way.

CASE STUDY

Dissecting a Duckbill

Excavators working in eastern Montana recovered a well-preserved thighbone of the duckbill dinosaur *Brachylophosaurus canadensis* in 2007. Microscopy revealed that the thighbone contained structures that resembled cells called osteocytes embedded in a matrix of white, fibrous material that looked like collagen protein (*micrograph*). Subsequent tests confirmed the presence of soft tissues and disproved the suggestion that the collagenlike and osteocytelike features might be derived from bacteria: extracts of the dinosaur's bone reacted with antibodies that target collagen and other proteins that bacteria do not make. And, as would be expected if the bone harbored dinosaur protein, readouts from a technique called mass spectrometry, which identifies the amino acid sequences in proteins, looked much like those from modern birds, which are descendants of dinosaurs, and unlike those from bacteria.



Brachylophosaurus canadensis

Osteocytes (*reddish branching structures*) and collagen (*white fibered matrix*) turned up in *Brachylophosaurus.*

COURTESY OF MARY H. SCHWEITZER (*micrograph*)

Illustration by Raúl Martin

Furthermore, when we then dissolved pieces of the denser, more common cortical bone, we obtained more soft tissue. Hollow, transparent, flexible, branching tubes emerged from the dissolving matrix—and they looked exactly like blood vessels. Suspended inside the vessels were either small, round red structures or amorphous accumulations of red material. Additional demineralization experiments revealed distinctive-looking bone cells called osteocytes that secrete the collagen and other components that make up the organic part of bone. The whole dinosaur seemed to preserve material never seen before in dinosaur bone.

When we published our observations in *Science* in 2005, reporting the presence of what looked to be collagen, blood vessels and bone cells, the paper garnered a lot of attention, but the scientific community adopted a wait-and-see attitude. We claimed only that the material we found resembled these modern components—not that they were one and the same. After millions of years, buried in sediments and exposed to geochemical conditions that varied over time, what was preserved in these bones might bear little chemical resemblance to what was there when the dinosaur was alive. The real value of these materials could be determined only if their composition could be discerned. Our work had just begun.

Using all the techniques honed while studying Big Mike, *Rahonavis, Shuvuuia* and the mammoth, I began an in-depth analysis of this *T. rex*'s bone in collaboration with Asara, who had refined the purification and sequencing methods we used in the mammoth study and was ready to try sequencing the dinosaur's much older proteins. This was a much harder exercise, because the concentration of organics in the dinosaur was orders of magnitude less than in the much younger mammoth and because the proteins were very degraded. Nevertheless, we were eventually able to sequence them. And, gratifyingly, when our colleague Chris Organ of Harvard compared the *T. rex* sequences with those of a multitude of other organisms, he found that they grouped most closely with birds, followed by crocodiles—the two groups that are the closest living relatives of dinosaurs.

CONTROVERSY AND ITS AFTERMATH

OUR PAPERS DETAILING the sequencing work, published in 2007 and 2008, generated a firestorm of controversy, most of which focused on our interpretations of the sequencing (mass spectrometry) data. Some dissenters charged that we had not produced enough sequences to make our case; others argued that the structures we interpreted as primeval soft tissues were actually biofilm—"slime" produced by microbes that had invaded the fossilized bone. There were other criticisms, too. I had mixed feelings about their feedback. On one hand, scientists are paid to be skeptical and to examine remarkable claims with rigor. On the other hand, science operates on the principle of parsimony—the simplest explanation for all the data is assumed to be the correct one. And we had supported our hypothesis with multiple lines of evidence.

Still, I knew that a single gee-whiz discovery does not have any long-term meaning to science. We had to sequence proteins from other dinosaur finds. When a volunteer accompanying us on a summer expedition found bones from an 80-million-year-old plant-eating duckbill dinosaur called *Brachylophosaurus canadensis,* or "Brachy," we suspected the duckbill might be a good source of ancient proteins even before we got its bones out of the ground. Hoping that it might contain organics, we did everything we could to free it from the surrounding sandstone quickly while minimizing its exposure to the elements. Air pollutants, humidity fluctuations and the like would be very harmful to fragile molecules, and the longer the bone was exposed, the more likely contamination and degradation would occur.

"Oh, my gosh, it's a girl—and it's pregnant!" I exclaimed to my assistant. She looked at me like I had lost my mind.

Perhaps because of this extra care—and prompt analyses—both the chemistry and the morphology of this second dinosaur were less altered than Brex's. As we had hoped, we found cells embedded in a matrix of white collagen fibers in the animal's bone. The cells exhibited long, thin, branchlike extensions that are characteristic of osteocytes, which we could trace from the cell body to where they connected to other cells. A few of them even contained what appeared to be internal structures, including possible nuclei.

Furthermore, extracts of the duckbill's bone reacted with antibodies that target collagen and other proteins that bacteria do not manufacture, refuting the suggestion that our soft-tissue structures were merely biofilms. In addition, the protein sequences we obtained from the bone most closely resembled those of modern birds, just as Brex's did. And we sent samples of the duckbill's bone to several different labs for independent testing, all of which confirmed our results. After we reported these findings in *Science* in 2009, I heard no complaints.

Our work does not stop here. There is still so much about ancient soft tissues that we do not understand. Why are these materials preserved when all our models say they should be degraded? How does fossilization really occur? How much can we learn about animals from preserved fragments of molecules? The sequencing work hints that analyses of this material might eventually help to sort out how extinct species are related—once we and others build up bigger libraries of ancient sequences, and sequences from living species, for comparison. As these databases expand, we may be able to compare sequences to see how members of a lineage changed at the molecular level. And by rooting these sequences in time, we might be able to better understand the rate of this evolution. Such insights will help scientists to piece together how dinosaurs and other extinct creatures responded to major environmental changes, how they recovered from catastrophic events, and ultimately what did them in. SA

MORE TO EXPLORE

Preservation of Biomolecules in Cancellous Bone of *Tyrannosaurus rex*. Mary H. Schweitzer et al. in *Journal of Vertebrate Paleontology*, Vol. 17, No. 2, pages 349–359; June 1997.

Beta-Keratin Specific Immunological Reactivity in Feather-like Structures of the Cretaceous Alvarezsaurid, *Shuvuuia deserti*. Mary H. Schweitzer et al. in *Journal of Experimental Zoology*, Vol. 285, pages 146–157; August 1999.

Protein Sequences from Mastodon and *Tyrannosaurus rex* Revealed by Mass Spectrometry. John M. Asara et al. in *Science*, Vol. 316, pages 280–285; April 13, 2007.

Dinosaurian Soft Tissues Interpreted as Bacterial Biofilms. Thomas G. Kaye et al. in *PLoS ONE*, Vol. 3, No. 7; July 2008.

Biomolecular Characterization and Protein Sequences of the Campanian Hadrosaur *B. canadensis*. Mary H. Schweitzer et al. in *Science*, Vol. 324, pages 626–631; May 1, 2009.

ANNOTATED LIST of additional resources and links **www.ScientificAmerican.com/dec2010**

BIOLOGY

Life Unseen

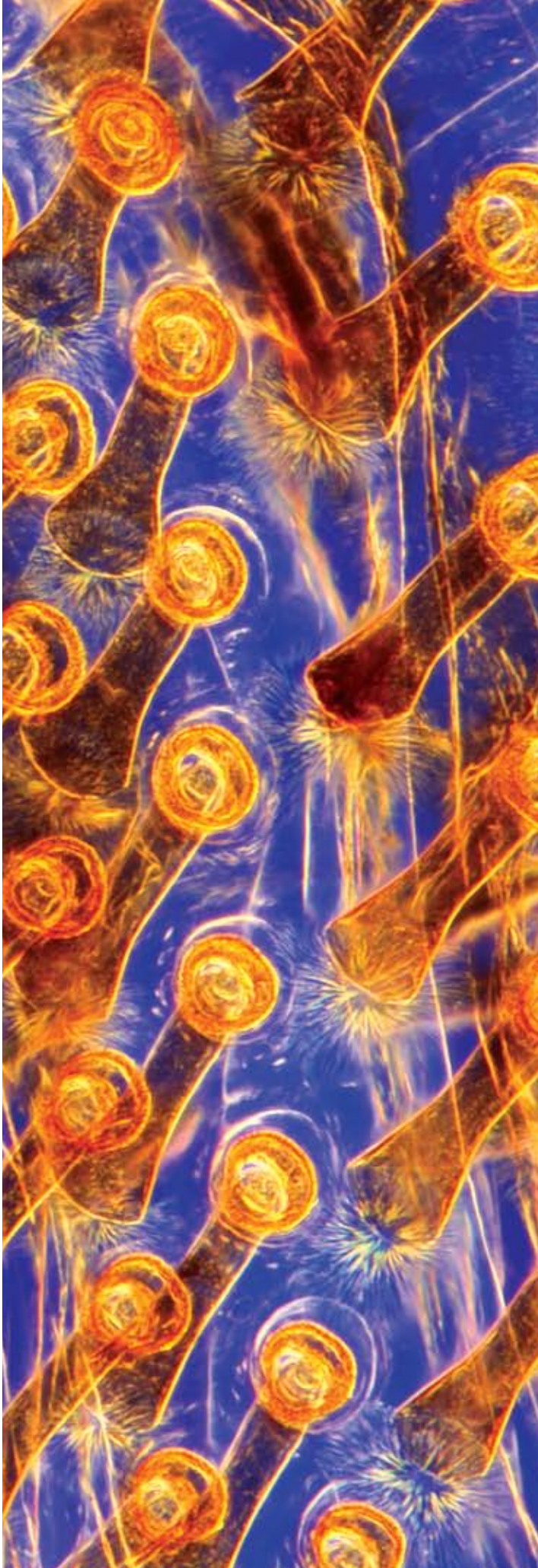
Microscopic landscapes show a surprising diversity of forms

By Davide Castelvecchi

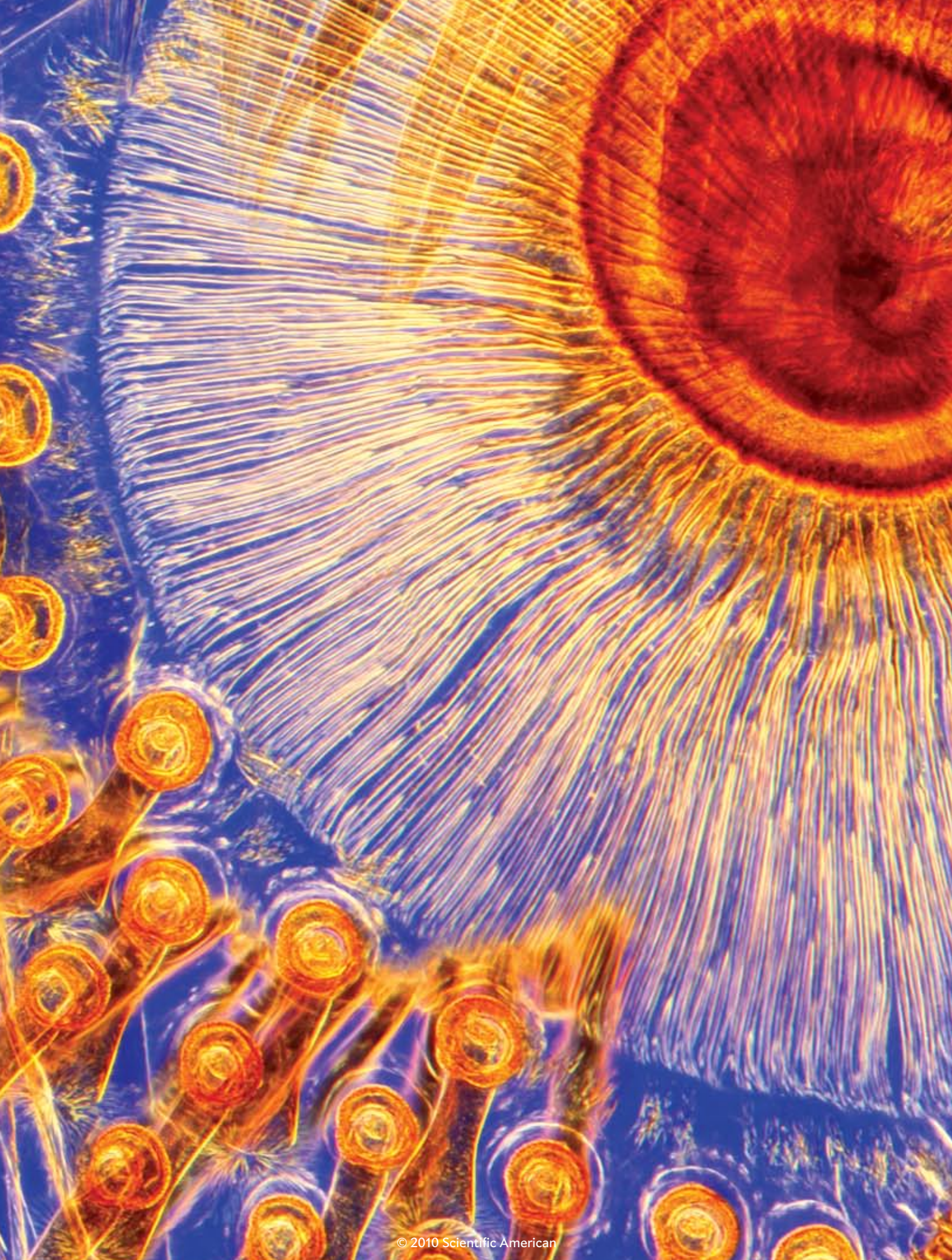
NATURE LOOKS FUNDAMENTALLY DIFFERENT DEpending on scale. This diversity is especially striking in the world of biology, where matter assembles itself in constantly renewing configurations, offering our eyes—aided by scientific instruments—limitless perspectives.

Thus, we can find beauty in places we did not suspect—inside a flower from a roadside weed, in the anatomical details of a flea or under a mushroom growing on a dead tree. Some people explore microscopic worlds for scientific reasons; others, such as Laurie Knight (*page 74*), for the sheer adventure. "The reason I do this," he says, "is that I get to see things that a lot of people can't really see."

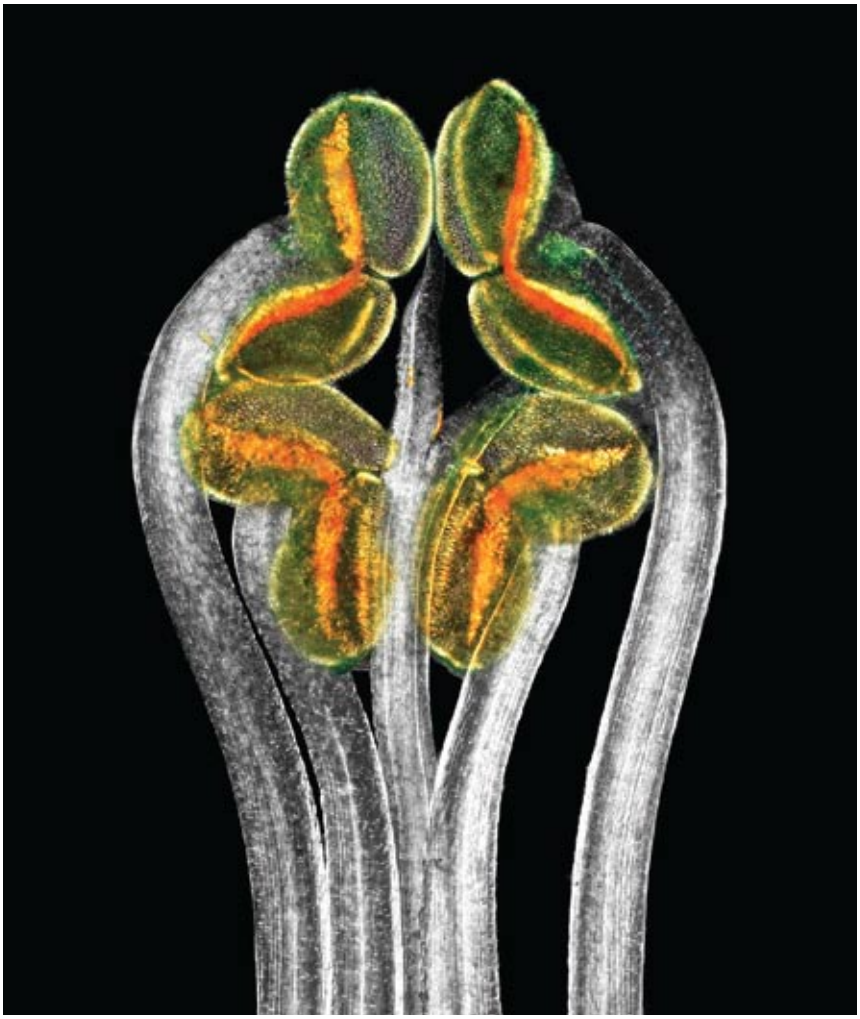
Fortunately, Knight and many others also like to share some of the vistas they discover. Every year scientists and hobbyists alike submit their microscopy art to the Olympus BioScapes International Digital Imaging Competition. These are images whose purpose is, in the words of another serious hobbyist, Edwin K. Lee (*page 72*), "to capture the combined essence of science and art." And, in turn, every year we at *Scientific American* like to share with readers some of our favorite shots from that competition. Enjoy. SA



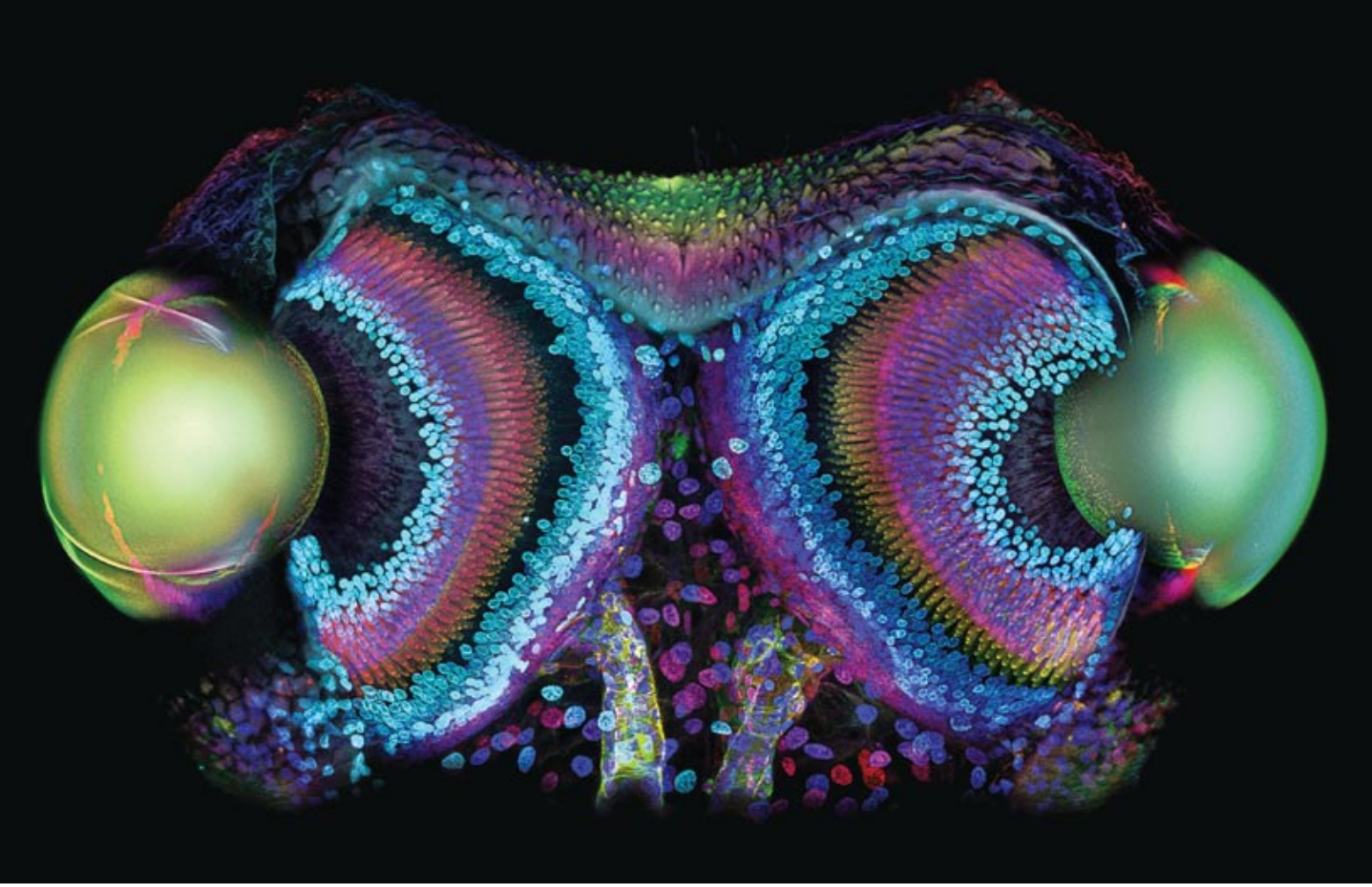
Beetle leg: **Spike Walker, a retired biology lecturer based in Penkridge, England, was striving for visual abstraction when he captured a detail of a *Dytiscus* water beetle's front leg. Walker used a type of darkfield microscopy in which the object is shot against a blue screen. The blue light shines through the orange of the leg's exoskeleton. The view, spanning about 1.8 millimeters in width, shows hair (*left* and *bottom*) and a suction cup (*large disk on right*). The males use these suction cups to hold on to females during mating. The image is patched together from 44 shots, each having a different focal plane.**

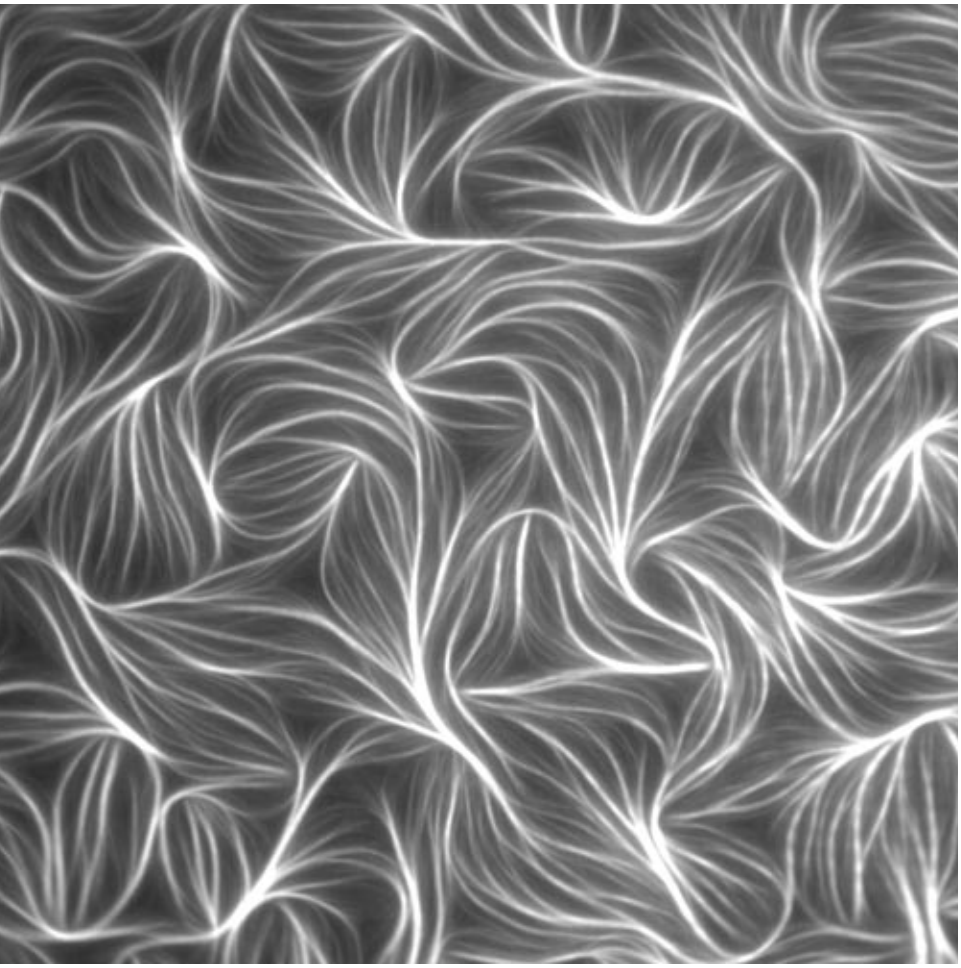


Weed stamens: The henbit deadnettle is a common weed. Edwin K. Lee, a retired microbiologist, picked one from the roadside near his home in Carrollton, Tex., to see if it might make an interesting subject for his microscope. He removed the stamens from the flowers and photographed them (*right*) using polarized light, to enhance the oranges and browns of the anthers, the pollen-carrying heads. The stamens are about three millimeters wide.



Blackfly larva: Tens of thousands of tiny creatures resembling polyps can sometimes be seen attached to rocks or aquatic plants on a single square meter of Normandy's riverbeds, extending their tentacles (or "cephalic fans") to capture particles of food, says Fabrice Parais, a hydrobiologist at the Regional Directorate for Environment, Land-Use Planning and Housing. But these creatures are not polyps; they are insects: larvae of blood-sucking blackflies. Parais catalogues and develops methods to analyze specimens such as the one below (which he conserved in formaldehyde and shot in darkfield microscopy) so that scientists can monitor biodiversity and thus spot signs of pressure on the ecosystem. Each tentacle is about two millimeters long.

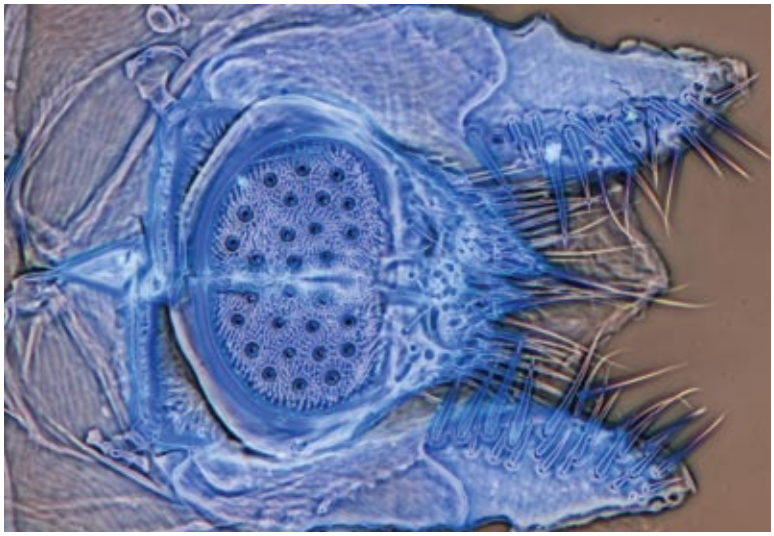




Spider eyes: First prize in the BioScapes competition went to Igor Siwanowicz of the Max Planck Institute for Neurobiology near Munich for his confocal microscope picture of the eyes of a daddy longlegs (*above*). The false-color image shows a cutaway view of the eyes, with the lenses (*two large ovals*), which are spaced less than a millimeter apart, and the retinas, which consist of a single layer of rodlike photoreceptor cells that give the spider rather poor, monochromatic vision. The photoreceptors' nuclei appear here as cyan, and the cells' elongated bodies are in a range of colors, from purple to reddish.

Actin filaments: Nucleated cells have an internal scaffolding called a cytoskeleton, made in part of filaments of the protein actin. The image at the left shows purified-actin filaments (tens of microns long) that Dennis Breitsprecher grew on a dish when he was a biochemistry graduate student at Hannover Medical School in Germany. Researchers are discovering hundreds of enzymes that regulate the evolving shape of the cytoskeleton, he says. But, he adds, only the right choice of enzymes produces the wavy shapes seen here: "I know what protein to add to make it look nice."

Flea organ: Vintage microscopy slides—especially those from the Victorian era—are collectors' items that hobbyists buy online or in specialized shops. David Walker, a retired petrol chemist from Huddersfield, England, produced the detail at the right of a flea specimen (showing a 0.7-millimeter-long sensory organ called a sensillum) by training his lens on a late-1800s or early-1900s prepared slide he bought on eBay for $15 or so. He altered the colors with photo-retouching software.



Honey mushroom: Reminiscent of the sensuous folds in some of Georgia O'Keeffe's paintings, the mushroom underside visible in the middle image was photographed by Neil Egan of Cleveland. Honey mushrooms are common around the facility where he works (as a quality-control technician for a manufacturer of automotive finishes); he found this one growing on a dead tree stump. Egan says he is not new to looking for beauty in ordinary objects: "The more you look at things, the more interesting they become."

Moth wing: We think of moths as grayish, boring-looking nocturnal bugs. But the sunset moth of Madagascar, or *Chrysiridia rhipheus,* is a diurnal creature with beautifully iridescent wings. Scales on the wings (*bottom*) have multiple layers of cuticle with varying nanometer-scale spacings between them that produce colors by optical interference. Laurie Knight, a Web developer in Tonbridge, England, took multiple shots of these scales with 20× magnification. He then used special software to meld the shots into one image on his "overclocked," made-to-spec computer.

Mushroom coral: The corals familiar to most of us are colonies of small polyps that build calcium carbonate branches. But mushroom corals, such as the one shown on the opposite page, are loners. James Nicholson, a retired medical-imaging specialist, photographed the five-centimeter-wide live specimen of an unidentified species for the Coral Culture and Collaborative Research Facility—a laboratory in Charleston, S.C., operated by the National Oceanic and Atmospheric Administration and other institutions—where he works as an unpaid consultant. Nicholson and his collaborators want to learn how to monitor environmental stress, such as that resulting from oil spills or rising temperatures. The small bumps are tentacles the animal uses to push food toward its mouth, which is the white slit in the middle.

MORE TO EXPLORE

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

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Roland R. Griffiths is a professor in the departments of psychiatry and neurosciences at the Johns Hopkins University School of Medicine. His principal research focus has been on the behavioral and subjective effects of mood-altering drugs. He is the lead investigator of the psilocybin research initiative at Johns Hopkins.

Charles S. Grob is a professor of psychiatry and pediatrics at the David Geffen School of Medicine at UCLA and director of the Division of Child and Adolescent Psychiatry at Harbor-UCLA Medical Center. He has conducted clinical research with several hallucinogenic drugs, including looking at psilocybin for treating anxiety in cancer patients.

HEALTH

Hallucinogens as Medicine

In a matter of hours, mind-altering substances may induce profound psychological realignments that can take decades to achieve on a therapist's couch

By Roland R. Griffiths and Charles S. Grob

SANDY LUNDAHL, A 50-YEAR-OLD HEALTH EDUCATOR, reported to the behavioral biology research center at the Johns Hopkins University School of Medicine one spring morning in 2004. She had volunteered to become a subject in one of the first studies of hallucinogenic drugs in the U.S. in more than three decades. She completed questionnaires, chatted with the two monitors who would be with her throughout the eight hours ahead, and settled herself in the comfortable, living-room-like space where the session would take place. She then swallowed two blue capsules and reclined on a couch. To help her relax and focus inward, she donned eyeshades and headphones, through which a program of specially selected classical music played.

The capsules contained a high dose of psilocybin, the principal constituent of "magic" mushrooms, which, like LSD and mescaline, produces changes in mood and perception yet only very rarely actual hallucinations. At the end of the session, when the psilocybin effects had dissipated, Lundahl, who had never before taken a hallucinogen, completed more questionnaires. Her responses indicated that during the time spent in the session room she had gone through a profound mystical-like experience similar to those reported by spiritual seekers in many cultures and across the ages—one characterized by a sense of interconnectedness with all people and things, accompanied by the feeling of transcending time and space, and of sacredness and joy.

IN BRIEF

Hundreds of research reports on hallucinogens appeared during the 1950s and 1960s. Illicit use resulted in outlawing of the drugs. Restrictions on research, moreover, brought studies to a halt.

Hints from the early set of studies suggesting that these chemicals might help treat patients with various psychiatric disorders were not pursued because of strictures on research.

A new wave of studies on hallucinogens, primarily psilocybin, has begun to address whether the drugs can effectively treat the anxiety of cancer patients or help addicts kick their habits.

Early results from new trials point to the promise of these therapies, with some patients reporting profound spiritual experiences and, hence , the ability to make important life changes.

Photograph by James Worrell

At a follow-up visit more than a year later, she said she continued to think about the experience every day and—most remarkably—that she regarded it as the most personally meaningful and spiritually significant event of her life. She felt it had brought on positive changes in her moods, attitudes and behaviors, as well as a noticeable increase in overall life satisfaction. "It seems like the experience triggered a quickening of my spiritual unfolding or development," she wrote. "Ripples of insight still occur... [I am] much more loving—making up for the past hurts I've inflicted... More and more I'm able to perceive people as having the light of the divine flowing through them."

Lundahl was one of 36 participants in a study conducted by one of us (Griffiths) at Johns Hopkins that began in 2001 and was published in 2006, with a follow-up report published two years later. When the initial paper appeared in the journal *Psychopharmacology,* many in the scientific community welcomed the revival of a research area that had long been dormant. Psilocybin studies at Johns Hopkins continue along two tracks: One explores the drug's psychospiritual effects in healthy volunteers. The other delves into whether hallucinogen-induced states of altered consciousness—and, in particular, mystical-like experiences—might ease various psychiatric and behavioral disorders, including some for which current therapies are not very effective. The main drug used in these studies is psilocybin, a so-called classic hallucinogen. As with other drugs in this class—psilocin, mescaline, DMT and LSD—psilocybin acts on brain cell receptors for the signaling molecule serotonin. Confusingly, substances from other drug classes that exert pharmacological effects different from those of the classic hallucinogens also bear the "hallucinogen" label in popular media and epidemiological reports. These compounds, some of which may also offer therapeutic potential, include ketamine, MDMA (which is familiar as "ecstasy"), salvinorin A and ibogaine, among others.

OVERCOMING LEARY'S LEGACY

THERAPEUTIC RESEARCH with hallucinogens pursues tantalizing evidence from studies begun in the 1950s that collectively involved thousands of participants. Some of these studies hinted that hallucinogens could help treat substance addiction and relieve the psychological distress of terminal illness. This research came to a halt in the early 1970s, as recreational use of the hallucinogens, mostly LSD, grew and garnered sensationalistic media coverage. The field had also been tainted by the widely publicized dismissal of Timothy Leary and Richard Alpert from Harvard University in 1963 in response to concerns about unconventional research methods using hallucinogens, including, in Alpert's case, giving psilocybin to a student off campus.

The burgeoning and unsupervised use of the little-understood substances, partly a result of Leary's charismatic advocacy, generated a backlash. The 1970 Controlled Substances Act placed common hallucinogens in Schedule I, its most restrictive category. New limitations were placed on human research, federal funding ceased, and investigators involved in this line of research found themselves professionally marginalized.

Decades passed before the anxiety-ridden attitudes that had blocked investigation subsided enough to allow rigorous human studies with these much storied substances. The mystical-like experiences brought about by hallucinogens interest researchers particularly because such experiences have the potential to produce rapid and enduring positive changes in moods and behavior—changes that might take years of effort to achieve with conventional psychological therapy. The Johns Hopkins work is so exciting because it demonstrates that such experiences can be elicited in a lab in most subjects studied. It permits, for the first time, rigorous, prospective scientific investigations that track volunteers before and after taking the drug. This type of study enables researchers to examine the causes and psychological and behavioral effects of these extraordinary experiences.

In its recent study the Johns Hopkins investigators used questionnaires originally designed to assess mystical experiences that occurred on their own without drugs. They also looked at overall psychological states at two and 14 months after the psilocybin session. The data showed that participants experienced increased self-confidence, a greater sense of inner contentment, a better ability to tolerate frustration, decreased nervousness and an increase in overall well-being. Ratings of their behavior by friends, family members and work colleagues uninformed about the drug experience were consistent with the participants' self-ratings. One typical comment from a subject: "The sense that all is One, that I experienced the essence of the universe and the knowing that God asks nothing of us except to receive love. I am not alone. I do not fear death. I am more patient with myself." Another participant was so inspired that she wrote an entire book about her experiences.

RELIEF OF SUFFERING

WHEN RESEARCH INTO hallucinogen-based therapy stalled some 40 years ago, it left a to-do list that included the treatment of alcoholism and other drug addictions, anxiety associated with cancer, obsessive-compulsive disorder, post-traumatic stress disorder, psychosomatic disorder, severe character pathology and autism. Back then, most published reports were anecdotal accounts of treatments with hallucinogens, furnishing much weaker evidence than that from controlled clinical trials. Even the best studies of the era did not incorporate the stringent control conditions and methodologies that have become standard in modern clinical psychopharmacology research.

With cancer, patients frequently confront severe anxiety and depression, and antidepressants and anxiety-reducing drugs may be of limited help. In the 1960s and early 1970s more than 200 cancer patients received classic hallucinogens in a series of clinical studies. In 1964 Eric Kast of Chicago Medical School, who administered LSD to terminal patients with severe pain, reported that the patients developed "a peculiar disregard for the gravity of their situations and talked freely about their impending death with an affect considered inappropriate in our Western civilization but most beneficial to their psychic states." Subsequent studies by Stanislav Grof, William Richards and their colleagues at Spring Grove State Hospital near Baltimore (and later at the Maryland Psychiatric Research Center) used LSD and another classic hallucinogen DPT (dipropyltryptamine). The trials showed decreases in depression, anxiety and fear of death, and patients who had a mystical-type experience had the most improvements in psychological measures of well-being.

One of us (Grob) has updated this work. In September a paper in the *Archives of General Psychiatry* reported on a 2004–2008 pilot study at the Harbor-UCLA Medical Center to assess whether psilocybin sessions reduced anxiety in 12 terminal cancer patients. Although the study was too small to yield definitive conclusions, it was encouraging: the patients showed diminished anxiety and

improved mood, even several months after the psilocybin session. As with studies conducted years ago, participants also reported less fear of impending death. Johns Hopkins and New York University have now undertaken studies with cancer patients using higher doses of psilocybin—ones more likely to induce the mystical-like experiences that earlier investigations indicated were pivotal to lasting therapeutic benefits. In Switzerland a similar pilot study has begun using LSD instead of psilocybin.

Alcoholics, cigarette smokers and other substance abusers sometimes report beating their addictions after a deeply affecting mystical experience that occurred spontaneously without drugs. The first wave of clinical hallucinogen research recognized the potential therapeutic power of these transformative experiences. More than 1,300 patients participated in addiction studies that yielded more than two dozen publications decades ago. Some of those studies administered high doses to minimally prepared patients with little psychological support, a few of whom were even physically strapped to their beds. Researchers who appreciated the importance of "set and setting" and who provided better support to patients tended to see better results. This earlier work yielded promising but inconclusive results.

The new generation of hallucinogen research, with its better methodologies, should be able to determine whether these drugs can in fact help people overcome their addictions. At Johns Hopkins, Griffiths, Matthew Johnson and their colleagues have begun a smoking cessation pilot study using psilocybin sessions to supplement cognitive-behavioral therapy, a form of treatment that teaches patients how to change their thoughts and behaviors to quit and remain abstinent.

Beyond treating addictions, studies have recently started to test whether psilocybin can help allay the symptoms of obsessive-compulsive disorder. Other controlled substances with different mechanisms of action are also showing therapeutic potential. Recent investigations demonstrated that ketamine, given in low doses (it is normally used as an anesthetic), could provide more rapid relief from depression than traditional antidepressants such as Prozac. A recent trial in South Carolina used MDMA to successfully treat post-traumatic stress disorder in patients whom conventional therapies had failed to help. Similar MDMA trials are under way in Switzerland and Israel.

RISKS AND THE ROAD AHEAD

FOR THERAPIES using the classic hallucinogens to gain acceptance, they will have to overcome concerns that emerged with the drug excesses of the "psychedelic '60s." Hallucinogens can sometimes induce anxiety, paranoia or panic, which in unsupervised settings can escalate to accidental injuries or suicide. In the Johns Hopkins study, even after careful screening and at least eight hours of preparation with a clinical psychologist, about a third of the participants experienced some period of significant fear and about a fifth felt paranoia sometime during the session. But in the supportive, homelike setting provided in the research center and with the constant presence of trained guides, the Johns Hopkins participants encountered no lasting ill effects.

Other potential risks of hallucinogens include prolonged psychosis, psychological distress, or disturbances in vision or other senses lasting days or even longer. Such effects occur infrequently and even more rarely in carefully screened and psychologically prepared volunteers. Although classic hallucinogens are sometimes abused (used in a manner that jeopardizes the safety of the users or others), they are not typically considered drugs of addiction, because they neither promote compulsive drug taking nor induce a withdrawal syndrome. To help minimize adverse reactions, the Johns Hopkins group recently published a set of safety guidelines for conducting high-dose hallucinogen studies. Given researchers' ability to manage drug risks, we feel that studies of these substances should continue because of their potential ability to transform the life of, say, a cancer patient or drug addict. If hallucinogens prove themselves useful in the treatment of substance abuse or the existential anxiety associated with life-threatening illness, further investigations could explore whether drug-induced experiences might be incorporated into therapies related to major public health problems, such as eating disorders, risky sexual behavior or a wider set of maladaptive behaviors.

The latest round of hallucinogen research is helping to determine whether these drugs can wean people from addictions or allay the anxiety of cancer patients.

Benefits may also come from neuroimaging and pharmacological techniques that did not exist in the 1960s, which provide a better understanding of how these drugs work. Imaging of the brain areas involved in the intense emotions and thoughts people have under the drugs' influence will provide a window into the underlying physiology of mystical-type experiences produced by hallucinogens. Further research may also yield non-pharmacological approaches that work more quickly and effectively than traditional spiritual practices such as meditation or fasting to produce mystical experiences and desired behavioral changes—the kind of experience that convinced Bill Wilson in Towns Hospital in New York City to stop drinking and inspired him to found Alcoholics Anonymous in the 1930s.

Understanding how mystical experiences can engender benevolent attitudes toward oneself and others will, in turn, aid in explaining the well-documented protective role of spirituality in psychological well-being and health. Mystical experiences can bring about a profound and enduring sense of the interconnectedness of all people and things—a perspective that underlies the ethical teachings of the world's religious and spiritual traditions. A grasp of the biology of the classic hallucinogens, then, could help clarify the mechanisms underlying human ethical and cooperative behavior—knowledge that, we believe, may ultimately be crucial to the survival of the human species. SA

MORE TO EXPLORE

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Johns Hopkins Psilocybin Cancer Project: **www.cancer-insight.org**

READ ABOUT A PSILOCYBIN EXPERIENCE **www.ScientificAmerican.com/psilocybin-book**

Tim Berners-Lee invented the World Wide Web. Today he is director of the international World Wide Web Consortium, based in the U.S. at the Massachusetts Institute of Technology. He is also a professor of engineering at M.I.T. and a professor of electronics and computer science at the University of Southampton in England.

INFORMATION SCIENCE

LONG LIVE THE WEB

The Web is critical not merely to the digital revolution but to our continued prosperity—and even our liberty. Like democracy itself, it needs defending

By Tim Berners-Lee

THE WORLD WIDE WEB WENT LIVE, ON MY PHYSICAL DESKTOP IN GENEVA, SWITZERLAND, in December 1990. It consisted of one Web site and one browser, which happened to be on the same computer. The simple setup demonstrated a profound concept: that any person could share information with anyone else, anywhere. In this spirit, the Web spread quickly from the grassroots up. Today, at its 20th anniversary, the Web is thoroughly integrated into our daily lives. We take it for granted, expecting it to "be there" at any instant, like electricity.

The Web evolved into a powerful, ubiquitous tool because it was built on egalitarian principles and because thousands of individuals, universities and companies have worked, both independently and together as part of the World Wide Web Consortium, to expand its capabilities based on those principles.

The Web as we know it, however, is being threatened in different ways. Some of its most successful inhabitants have begun to chip away at its principles. Large social-networking sites are walling off information posted by their users from the rest of the Web. Wireless Internet providers are being tempted to slow traffic to sites with which they have not made deals. Governments—totalitarian and democratic alike—are monitoring people's online habits, endangering important human rights.

Illustration by John Hendrix

If we, the Web's users, allow these and other trends to proceed unchecked, the Web could be broken into fragmented islands. We could lose the freedom to connect with whichever Web sites we want. The ill effects could extend to smartphones and pads, which are also portals to the extensive information that the Web provides.

Why should you care? Because the Web is yours. It is a public resource on which you, your business, your community and your government depend. The Web is also vital to democracy, a communications channel that makes possible a continuous worldwide conversation. The Web is now more critical to free speech than any other medium. It brings principles established in the U.S. Constitution, the British Magna Carta and other important documents into the network age: freedom from being snooped on, filtered, censored and disconnected.

Yet people seem to think the Web is some sort of piece of nature, and if it starts to wither, well, that's just one of those unfortunate things we can't help. Not so. We create the Web, by designing computer protocols and software; this process is completely under our control. We choose what properties we want it to have and not have. It is by no means finished (and it's certainly not dead). If we want to track what government is doing, see what companies are doing, understand the true state of the planet, find a cure for Alzheimer's disease, not to mention easily share our photos with our friends, we the public, the scientific community and the press must make sure the Web's principles remain intact—not just to preserve what we have gained but to benefit from the great advances that are still to come.

UNIVERSALITY IS THE FOUNDATION

SEVERAL PRINCIPLES ARE KEY to assuring that the Web becomes ever more valuable. The primary design principle underlying the Web's usefulness and growth is universality. When you make a link, you can link to anything. That means people must be able to put anything on the Web, no matter what computer they have, software they use or human language they speak and regardless of whether they have a wired or wireless Internet connection. The Web should be usable by people with disabilities. It must work with any form of information, be it a document or a point of data, and information of any quality—from a silly tweet to a scholarly paper. And it should be accessible from any kind of hardware that can connect to the Internet: stationary or mobile, small screen or large.

These characteristics can seem obvious, self-maintaining or just unimportant, but they are why the next blockbuster Web site or the new homepage for your kid's local soccer team will just appear on the Web without any difficulty. Universality is a big demand, for any system.

Decentralization is another important design feature. You do not have to get approval from any central authority to add a page or make a link. All you have to do is use three simple, standard protocols: write a page in the HTML (hypertext markup language) format, name it with the URI naming convention, and serve it up on the Internet using HTTP (hypertext transfer protocol). Decentralization has made widespread innovation possible and will continue to do so in the future.

The URI is the key to universality. (I originally called the naming scheme URI, for universal resource identifier; it has come to be known as URL, for uniform resource locator.) The URI allows you to follow any link, regardless of the content it leads to or who publishes that content. Links turn the Web's content into something of greater value: an interconnected information space.

Several threats to the Web's universality have arisen recently. Cable television companies that sell Internet connectivity are considering whether to limit their Internet users to downloading only the company's mix of entertainment. Social-networking sites present a different kind of problem. Facebook, LinkedIn, Friendster and others typically provide value by capturing information as you enter it: your birthday, your e-mail address, your likes, and links indicating who is friends with whom and who is in which photograph. The sites assemble these bits of data into brilliant databases and reuse the information to provide value-added service—but only within their sites. Once you enter your data into one of these services, you cannot easily use them on another site. Each site is a silo, walled off from the others. Yes, your site's pages are on the Web, but your data are not. You can access a Web page about a list of people you have created in one site, but you cannot send that list, or items from it, to another site.

The isolation occurs because each piece of information does not have a URI. Connections among data exist only within a site. So the more you enter, the more you become locked in. Your social-networking site becomes a central platform—a closed silo of content, and one that does not give you full control over your information in it. The more this kind of architecture gains widespread use, the more the Web becomes fragmented, and the less we enjoy a single, universal information space.

A related danger is that one social-networking site—or one search engine or one browser—gets so big that it becomes a monopoly, which tends to limit innovation. As has been the case since the Web began, continued grassroots innovation may be the best check and balance against any one company or government that tries to undermine universality. GnuSocial and Diaspora are projects on the Web that allow anyone to create their own social network from their own server, connecting to anyone on any other site. The Status.net project, which runs sites such as identi.ca, allows you to operate your own Twitter-like network without the Twitter-like centralization.

OPEN STANDARDS DRIVE INNOVATION

ALLOWING ANY SITE TO LINK to any other site is necessary but not sufficient for a robust Web. The basic Web technologies that individuals and companies need to develop powerful services must be available for free, with no royalties. Amazon.com, for exam-

IN BRIEF

The principle of universality allows the Web to work no matter what hardware, software, network connection or language you use and to handle information of all types and qualities. This principle guides Web technology design.

Technical standards that are open and royalty-free allow people to create applications without anyone's permission or having to pay. Patents, and Web services that do not use the common URIs for addresses, limit innovation.

Threats to the Internet, such as companies or governments that interfere with or snoop on Internet traffic, compromise basic human network rights.

Web applications, linked data and other future Web technologies will flourish only if we protect the medium's basic principles.

ple, grew into a huge online bookstore, then music store, then store for all kinds of goods because it had open, free access to the technical standards on which the Web operates. Amazon, like any other Web user, could use HTML, URI and HTTP without asking anyone's permission and without having to pay. It could also use improvements to those standards developed by the Web Consortium, allowing customers to fill out a virtual order form, pay online, rate the goods they had purchased, and so on.

By "open standards" I mean standards that can have any committed expert involved in the design, that have been widely reviewed as acceptable, that are available for free on the Web, and that are royalty-free (no need to pay) for developers and users. Open, royalty-free standards that are easy to use create the diverse richness of Web sites, from the big names such as Amazon, Craigslist and Wikipedia to obscure blogs written by adult hobbyists and to homegrown videos posted by teenagers.

Openness also means you can build your own Web site or company without anyone's approval. When the Web began, I did not have to obtain permission or pay royalties to use the Internet's own open standards, such as the well-known transmission control protocol (TCP) and Internet protocol (IP). Similarly, the Web Consortium's royalty-free patent policy says that the companies, universities and individuals who contribute to the development of a standard must agree they will not charge royalties to anyone who may use the standard.

Open, royalty-free standards do not mean that a company or individual cannot devise a blog or photo-sharing program and charge you to use it. They can. And you might want to pay for it if you think it is "better" than others. The point is that open standards allow for many options, free and not.

Indeed, many companies spend money to develop extraordinary applications precisely because they are confident the applications will work for anyone, regardless of the computer hardware, operating system or Internet service provider (ISP) they are using—all made possible by the Web's open standards. The same confidence encourages scientists to spend thousands of hours devising incredible databases that can share information about proteins, say, in hopes of curing disease. The confidence encourages governments such as those of the U.S. and the U.K. to put more and more data online so citizens can inspect them, making government increasingly transparent. Open standards also foster serendipitous creation: someone may use them in ways no one imagined. We discover that on the Web every day.

In contrast, not using open standards creates closed worlds. Apple's iTunes system, for example, identifies songs and videos using URIs that are open. But instead of "http:" the addresses begin with "itunes:," which is proprietary. You can access an "itunes:" link only using Apple's proprietary iTunes program. You can't make a link to any information in the iTunes world—a song or information about a band. You can't send that link to someone else to see. You are no longer on the Web. The iTunes world is centralized and walled off. You are trapped in a single store, rather than being on the open marketplace. For all the store's wonderful features, its evolution is limited to what one company thinks up.

Other companies are also creating closed worlds. The tendency for magazines, for example, to produce smartphone "apps" rather than Web apps is disturbing, because that material is off the Web. You can't bookmark it or e-mail a link to a page within it. You can't tweet it. It is better to build a Web app that will also run on smartphone browsers, and the techniques for doing so are getting better all the time.

Some people may think that closed worlds are just fine. The worlds are easy to use and may seem to give those people what they want. But as we saw in the 1990s with the America Online dial-up information system that gave you a restricted subset of the Web, these closed, "walled gardens," no matter how pleasing, can never compete in diversity, richness and innovation with the mad, throbbing Web market outside their gates. If a walled garden has too tight a hold on a market, however, it can delay that outside growth.

KEEP THE WEB SEPARATE FROM THE INTERNET

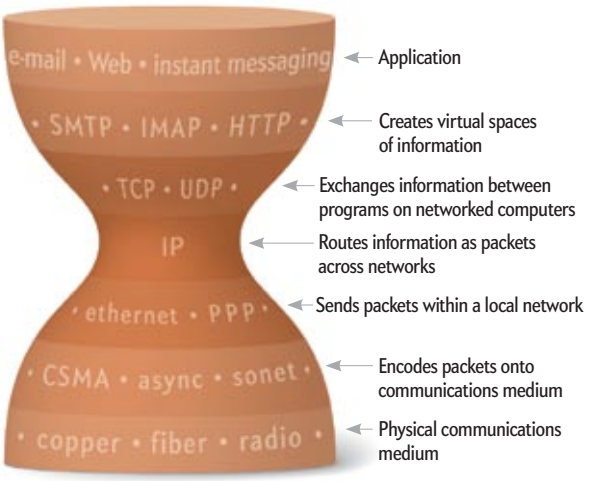
KEEPING THE WEB UNIVERSAL and keeping its standards open help people invent new services. But a third principle—the separation of layers—partitions the design of the Web from that of the Internet.

This separation is fundamental. The Web is an application that runs on the Internet, which is an electronic network that transmits packets of information among millions of computers according to a few open protocols. An analogy is that the Web is like a household appliance that runs on the electricity network. A refrigerator or printer can function as long as it uses a few standard protocols—in the U.S., things like operating at 120 volts and 60 hertz. Similarly, any application—among them the Web, e-mail or instant messaging—can run on the Internet as long as it uses a few standard Internet protocols, such as TCP and IP.

HOW IT WORKS

Web or Internet?

The Web is an application that runs on the Internet. So is instant messaging. The Internet is an electronic network that parcels application information into packets and ships them among computers over wires and wireless media, according to simple protocols (rules) known by various acronyms. The Internet and applications can be thought of as a stack of conceptual layers; each layer uses the services of the one below. Applications can be thought of as home appliances that tap into the electrical network in a standard way.



Graphic by Jen Christiansen

Manufacturers can improve refrigerators and printers without altering how electricity functions, and utility companies can improve the electrical network without altering how appliances function. The two layers of technology work together but can advance independently. The same is true for the Web and the Internet. The separation of layers is crucial for innovation. In 1990 the Web rolled out over the Internet without any changes to the Internet itself, as have all improvements since. And in that time, Internet connections have sped up from 300 bits per second to 300 million bits per second (Mbps) without the Web having to be redesigned to take advantage of the upgrades.

LOOKING AHEAD

The Future Web in Action

Several exciting trends that build on the Web's core principles are under way that could change how the online and physical worlds work. See "More to Explore" on the opposite page for a link to commentary and visuals on these four trends:

OPEN DATA

Putting data on the Web and linking them is bringing dynamic new capabilities to people everywhere. It has already helped cyclists avoid accidents in London, revealed discrimination in Ohio, and helped rescue teams aid people in Haiti after the massive earthquake this past January.

SOCIAL MACHINES

Lots of people post reviews and ratings of restaurants, which influence choices made by future patrons. This activity is one example of a social machine. More intricate social machines are being designed that can improve how science is done and how democracy is carried out.

WEB SCIENCE

We have only scratched the surface of understanding how the Web reflects the real world and shapes it. Web science, a new discipline being pursued at various institutions, is revealing intriguing insights into the Web's design, operation and impact on society.

FREE BANDWIDTH

Few people in developing countries can afford Internet access. Free, very low bandwidth service could greatly improve education, health and the economy in these regions yet at the same time encourage some people to upgrade to faster, paid service.

ELECTRONIC HUMAN RIGHTS

ALTHOUGH INTERNET AND WEB DESIGNS are separate, a Web user is also an Internet user and therefore relies on an Internet that is free from interference. In the early Web days it was too technically difficult for a company or country to manipulate the Internet to interfere with an individual Web user. Technology for interference has become more powerful, however. In 2007 BitTorrent, a company whose "peer-to-peer" network protocol allows people to share music, video and other files directly over the Internet, complained to the Federal Communications Commission that the ISP giant Comcast was blocking or slowing traffic to subscribers who were using the BitTorrent application. The FCC told Comcast to stop the practice, but in April 2010 a federal court ruled the FCC could not require Comcast to do so. A good ISP will often manage traffic so that when bandwidth is short, less crucial traffic is dropped, in a transparent way, so users are aware of it. An important line exists between that action and using the same power to discriminate.

This distinction highlights the principle of net neutrality. Net neutrality maintains that if I have paid for an Internet connection at a certain quality, say, 300 Mbps, and you have paid for that quality, then our communications should take place at that quality. Protecting this concept would prevent a big ISP from sending you video from a media company it may own at 300 Mbps but sending video from a competing media company at a slower rate. That amounts to commercial discrimination. Other complications could arise. What if your ISP made it easier for you to connect to a particular online shoe store and harder to reach others? That would be powerful control. What if the ISP made it difficult for you to go to Web sites about certain political parties, or religions, or sites about evolution?

Unfortunately, in August, Google and Verizon for some reason suggested that net neutrality should not apply to mobile phone–based connections. Many people in rural areas from Utah to Uganda have access to the Internet only via mobile phones; exempting wireless from net neutrality would leave these users open to discrimination of service. It is also bizarre to imagine that my fundamental right to access the information source of my choice should apply when I am on my WiFi-connected computer at home but not when I use my cell phone.

A neutral communications medium is the basis of a fair, competitive market economy, of democracy, and of science. Debate has risen again in the past year about whether government legislation is needed to protect net neutrality. It is. Although the Internet and Web generally thrive on lack of regulation, some basic values have to be legally preserved.

NO SNOOPING

OTHER THREATS TO THE WEB result from meddling with the Internet, including snooping. In 2008 one company, Phorm, devised a way for an ISP to peek inside the packets of information it was sending. The ISP could determine every URI that any customer was browsing. The ISP could then create a profile of the sites the user went to in order to produce targeted advertising.

Accessing the information within an Internet packet is equivalent to wiretapping a phone or opening postal mail. The URIs that people use reveal a good deal about them. A company that

Illustration by John Hendrix

bought URI profiles of job applicants could use them to discriminate in hiring people with certain political views, for example. Life insurance companies could discriminate against people who have looked up cardiac symptoms on the Web. Predators could use the profiles to stalk individuals. We would all use the Web very differently if we knew that our clicks can be monitored and the data shared with third parties.

Free speech should be protected, too. The Web should be like a white sheet of paper: ready to be written on, with no control over what is written. Earlier this year Google accused the Chinese government of hacking into its databases to retrieve the e-mails of dissidents. The alleged break-ins occurred after Google resisted the government's demand that the company censor certain documents on its Chinese-language search engine.

Totalitarian governments aren't the only ones violating the network rights of their citizens. In France a law created in 2009, named Hadopi, allowed a new agency by the same name to disconnect a household from the Internet for a year if someone in the household was *alleged* by a media company to have ripped off music or video. After much opposition, in October the Constitutional Council of France required a judge to review a case before access was revoked, but if approved, the household could be disconnected without due process. In the U.K., the Digital Economy Act, hastily passed in April, allows the government to order an ISP to terminate the Internet connection of anyone who appears on a list of individuals suspected of copyright infringement. In September the U.S. Senate introduced the Combating Online Infringement and Counterfeits Act, which would allow the government to create a blacklist of Web sites—hosted on or off U.S. soil—that are accused of infringement and to pressure or require all ISPs to block access to those sites.

In these cases, no due process of law protects people before they are disconnected or their sites are blocked. Given the many ways the Web is crucial to our lives and our work, disconnection is a form of deprivation of liberty. Looking back to the Magna Carta, we should perhaps now affirm: "No person or organization shall be deprived of the ability to connect to others without due process of law and the presumption of innocence."

When your network rights are violated, public outcry is crucial. Citizens worldwide objected to China's demands on Google, so much so that Secretary of State Hillary Clinton said the U.S. government supported Google's defiance and that Internet freedom—and with it, Web freedom—should become a formal plank in American foreign policy. In October, Finland made broadband access, at 1 Mbps, a legal right for all its citizens.

LINKING TO THE FUTURE

AS LONG AS THE WEB'S BASIC PRINCIPLES are upheld, its ongoing evolution is not in the hands of any one person or organization—neither mine nor anyone else's. If we can preserve the principles, the Web promises some fantastic future capabilities.

For example, the latest version of HTML, called HTML5, is not just a markup language but a computing platform that will make Web apps even more powerful than they are now. The proliferation of smartphones will make the Web even more central to our lives. Wireless access will be a particular boon to developing countries, where many people do not have connectivity by wire or cable but do have it wirelessly. Much more needs to be done, of course, including accessibility for people with disabilities and devising pages that work well on all screens, from huge 3-D displays that cover a wall to wristwatch-size windows.

A great example of future promise, which leverages the strengths of all the principles, is linked data. Today's Web is quite effective at helping people publish and discover documents, but our computer programs cannot read or manipulate the actual data within those documents. As this problem is solved, the Web will become much more useful, because data about nearly every aspect of our lives are being created at an astonishing rate. Locked within all these data is knowledge about how to cure diseases, foster business value and govern our world more effectively.

Scientists are actually at the forefront of some of the largest efforts to put linked data on the Web. Researchers, for example, are realizing that in many cases no single lab or online data repository is sufficient to discover new drugs. The information necessary to understand the complex interactions between diseases, biological processes in the human body, and the vast array of chemical agents is spread across the world in a myriad of databases, spreadsheets and documents.

One success relates to drug discovery to combat Alzheimer's disease. A number of corporate and government research labs dropped their usual refusal to open their data and created the Alzheimer's Disease Neuroimaging Initiative. They posted a massive amount of patient information and brain scans as linked data, which they have dipped into many times to advance their research. In a demonstration I witnessed, a scientist asked the question, "What proteins are involved in signal transduction and are related to pyramidal neurons?" When put into Google, the question got 233,000 hits—and not one single answer. Put into the linked databases world, however, it returned a small number of specific proteins that have those properties.

The investment and finance sectors can benefit from linked data, too. Profit is generated, in large part, from finding patterns in an increasingly diverse set of information sources. Data are all over our personal lives as well. When you go onto your social-networking site and indicate that a newcomer is your friend, that establishes a relationship. And that relationship is data.

Linked data raise certain issues that we will have to confront. For example, new data-integration capabilities could pose privacy challenges that are hardly addressed by today's privacy laws. We should examine legal, cultural and technical options that will preserve privacy without stifling beneficial data-sharing capabilities.

Now is an exciting time. Web developers, companies, governments and citizens should work together openly and cooperatively, as we have done thus far, to preserve the Web's fundamental principles, as well as those of the Internet, ensuring that the technological protocols and social conventions we set up respect basic human values. The goal of the Web is to serve humanity. We build it now so that those who come to it later will be able to create things that we cannot ourselves imagine. SA

MORE TO EXPLORE

Creating a Science of the Web. Tim Berners-Lee et al. in *Science*, Vol. 313; August 11, 2006.
Also, see the Web Science Research Initiative: **www.webscience.org**
Notes by Tim Berners-Lee on Web design and other matters: **www.w3.org/DesignIssues**.
The World Wide Web Consortium's main page is **www.w3.org**
The World Wide Web Foundation funds and coordinates efforts that see to it that the Web serves humanity: **www.webfoundation.org**

MORE ON THE WEB'S FUTURE **www.ScientificAmerican.com/dec2010/berners-lee**

LIFE SCIENCE

Jane of the Jungle

Primatologist Jane Goodall shares insights from her 50 years among chimpanzees

Interview by Kate Wong

On July 4, 1960, 26-year-old Jane Goodall arrived at Gombe Stream Game Reserve in Tanzania to study the behavior of chimpanzees. Through her accounts of the drama-filled lives of Fifi, David Greybeard and other chimps, she showed that these apes share many traits previously thought to be unique to humans. These days the 76-year-old Goodall works to save endangered chimps and their habitats. Scientific American recently reached Goodall by phone in Hong Kong, where she was commemorating the 50th anniversary of the start of her work in Gombe. Edited excerpts from the conversation follow.

Scientific American: When you first arrived at Gombe, what were your preconceptions about chimpanzees?

Goodall: I was expecting chimpanzees to be highly intelligent, but as for how they lived in the wild or what their social structure was, nobody knew much about that.

What about their behavior most surprised you?

The most significant thing is how incredibly like humans they are. Many people were really surprised by the fact that they made and used tools. That didn't surprise me particularly, because German psychologist Wolfgang Köhler had reported that they use tools readily in captivity. But it was exciting to observe this behavior in the wild, along with hunting and food sharing, because it enabled us to get money to carry on with our research.

What came as a shock to me is that, like us, they have a very dark side, and they're capable of violent brutality, even war. Communities will engage in a sort of primitive warfare that appears to be over territory. Perhaps even more shocking are the attacks on newborn babies by females in the same community.

What sets the human mind apart from the chimp mind?

The explosive development of intellect. You can have very bright chimps that can learn sign language and do all kinds of things with computers, but it doesn't make sense to compare that intellect with even that of a normal human, let alone an Einstein. My own feeling is that the evolution of our intellect quickened once we began using the kind of language we use today, a language that enables us to discuss the past and to plan the distant future.

How are chimpanzees faring in the wild?

They're not doing well at all. The main threats vary from place to place, but in most locations the biggest problem is the loss of their forests. In the Congo Basin, where the main chimp populations exist, the illegal commercial bushmeat trade is another threat, and that's pretty grim. Chimpanzees can also catch many of our infectious diseases, so as logging companies make roads deeper into the forest, the animals are more at risk.

What is being done now to protect chimps?

In Tanzania the Jane Goodall Institute started a program called TACARE ("Take Care"), which is improving the lives of the local villagers by helping to alleviate poverty, so they now want to support our efforts to protect the forest. They understand the importance of conserving water by not cutting the trees down. Gombe is very tiny, but it now has a buffer of green growing all the way around the park where once there were bare hills. We have the beginnings of corridors moving out to other tropical forests with small groups of chimps in them. We have no idea if the animals will use these corridors, but at least we're giving them the option.

Another development is the Reducing Emissions from Deforestation and Forest Degradation (REDD) initiative, a funding mechanism that could direct money from carbon trading to communities that can prove they are protecting their forests. With grant money we received from the Royal Norwegian Embassy of Tanzania this year, we are helping communities to participate in REDD by, among other things, working with Google Earth Outreach to train local people to use the Android smartphone and other technologies to collect carbon data and monitor their forests.

What have been your most significant contributions?

Breaking down this perceived sharp line between us and other creatures. I think chimpanzees have helped people understand that we are part of and not separated from the animal kingdom, and that has opened the way to having respect for the other amazing beings with whom we share the planet.

Young people everywhere need to realize that what we do individually every day does make a difference. If everybody begins thinking of the consequences of the little choices they make—what they eat, what they wear, what they buy, how they get from A to B—and acting accordingly, these millions of small changes will create the kinds of larger changes we must have if we care at all for our children. This is why I'm on the road 300 days a year talking to groups of youths as well as adults, politicians and businesses—because I don't think we've got that much time left. SA

MORE COMMENTARY FROM GOODALL (including answers to questions posed by readers on Facebook) www.ScientificAmerican.com/dec2010/Goodall

PHILIPP HORAK Redux Pictures

David H. Freedman has been covering science, business and technology for 30 years in publications such as the *Atlantic*, *Newsweek*, the *New York Times*, *Science*, *Wired* and *Technology Review*. His most recent book, *Wrong*, explores the forces that lead scientists and other top experts to mislead us.

SPACE EXPLORATION

Jump-Starting the Orbital Economy

Why NASA's plan to get out of the manned spaceflight business may (finally) make space travel routine

By David H. Freedman

TWO YEARS AGO DECEASED *STAR TREK* ACTOR JAMES "SCOTTY" DOOHAN WAS GRANTED one last adventure, courtesy of Space Exploration Technologies Corporation. SpaceX, a privately funded company based in Hawthorne, Calif., had been formed in 2002 with the mission of going where no start-up had gone before: Earth orbit. In August 2008 SpaceX loaded Doohan's cremated remains onto the third test flight of its Falcon 1, a liquid oxygen- and kerosene-fueled rocket bound for orbit. Yet about two minutes into the flight Doohan's final voyage ended prematurely when the rocket's first stage crashed into the second stage during separation. It was SpaceX's third failure in three attempts.

IN BRIEF

The shuttle is out. When NASA retires the space shuttle in the middle of next year, the U.S. will no longer be able to launch astronauts or supplies to the International Space Station.

Private companies are in. The Obama administration has canceled Constellation, the planned successor to the shuttle, and instead plans to rely on private companies to ferry astronauts.

Hopes are high. In theory, early government support of daring entrepreneurs could jump-start a vibrant economy centered on space travel, with competition pushing prices ever lower.

Risks are, too. Yet no one knows if start-up companies will be able to deliver safe, affordable, reliable spacecraft. If they fail, human exploration of space could be set back by decades.

Illustration by John Mattos

Well, what did you expect? sneered old NASA hands, aerospace executives and the many others who hew to the conventional wisdom that safely ushering payloads and especially people hundreds of kilometers above Earth is a job for no less than armies of engineers, technicians and managers backed by billions in funding and decades-long development cycles. Space, after all, is *hard*. A small, private operation might be able to send a little stunt ship wobbling up tens of kilometers, as entrepreneur-engineer Burt Rutan did in 2004 to win the X-Prize. But that was a parlor trick compared with the kinds of operations NASA has been running over the years with the space shuttle and International Space Station. When you're going orbital, 100 kilometers is merely the length of the driveway, at the end of which you'd better be accelerating hard toward the seven kilometers a second needed to keep a payload falling around Earth 300 kilometers up.

What, then, could the Obama administration have been thinking when it announced this past February that NASA should essentially get out of the manned-spaceship business and turn it over to private industry? Under the plan, NASA will write off most of the $9 billion invested so far in Constellation, the program to develop a replacement vehicle for the space shuttle capable of ferrying astronauts and supplies to the space station and, eventually, to the moon. Instead the agency will provide seed money to start-ups such as SpaceX, then agree to buy tickets to the space station on their rockets.

It is a naive and reckless plan, a chorus of voices charged. Among the loudest was that of former astronaut and space icon Neil Armstrong, who was quick to scoff at the notion that the private sector is ready to take over from NASA. "It will require many years and substantial investment to reach the necessary level of safety and reliability," he stated. Leaving orbital ferrying in the hands of private companies, Armstrong and others insisted, would at best be setting the clock back on manned space exploration. And were private enterprise to drop the ball, perhaps even catastrophically, as many believe it would, the entire grand enterprise of sending people into space might come to a long-term or even permanent halt. Once NASA's massive manned-spaceflight machine is dismantled, rebuilding it might take far more time and money than anyone would want to spend. Yet despite these concerns, Congress reluctantly agreed to the plan this fall.

But just because it is a big bet with real risks does not mean it is a *bad* bet. There are reasons to believe private companies could quickly rise to the task of getting people to orbit—and do it more cheaply and reliably than any big NASA-run program ever could. And that in turn could open the door to a prize that, thanks to a three-decade-long near stall in human space exploration, most people had almost stopped even dreaming about: a welcome mat above Earth not just for a small corps of astronauts but also for legions of scientists, engineers and even those of us who would simply get a really big kick out of spending a few days or weeks in outer space. Even better, the wave of space visitors could kick-start a self-sustaining orbital economy, one that would establish humanity's place in space, including Mars and beyond, much more firmly than Constellation or any conventional space program ever could.

LETTING GO

RELYING ON THE COMMERCIAL SECTOR to build spacecraft would not be a new development, of course. The extraordinary vehicles that have carried NASA's astronauts into space have always been developed and built by companies. What will change under the plan is the *way* NASA will work with private firms. As with the Pentagon, NASA hires contractors on a "cost-plus" basis, which means NASA reimburses them for whatever they spend and then tosses in a guaranteed profit.

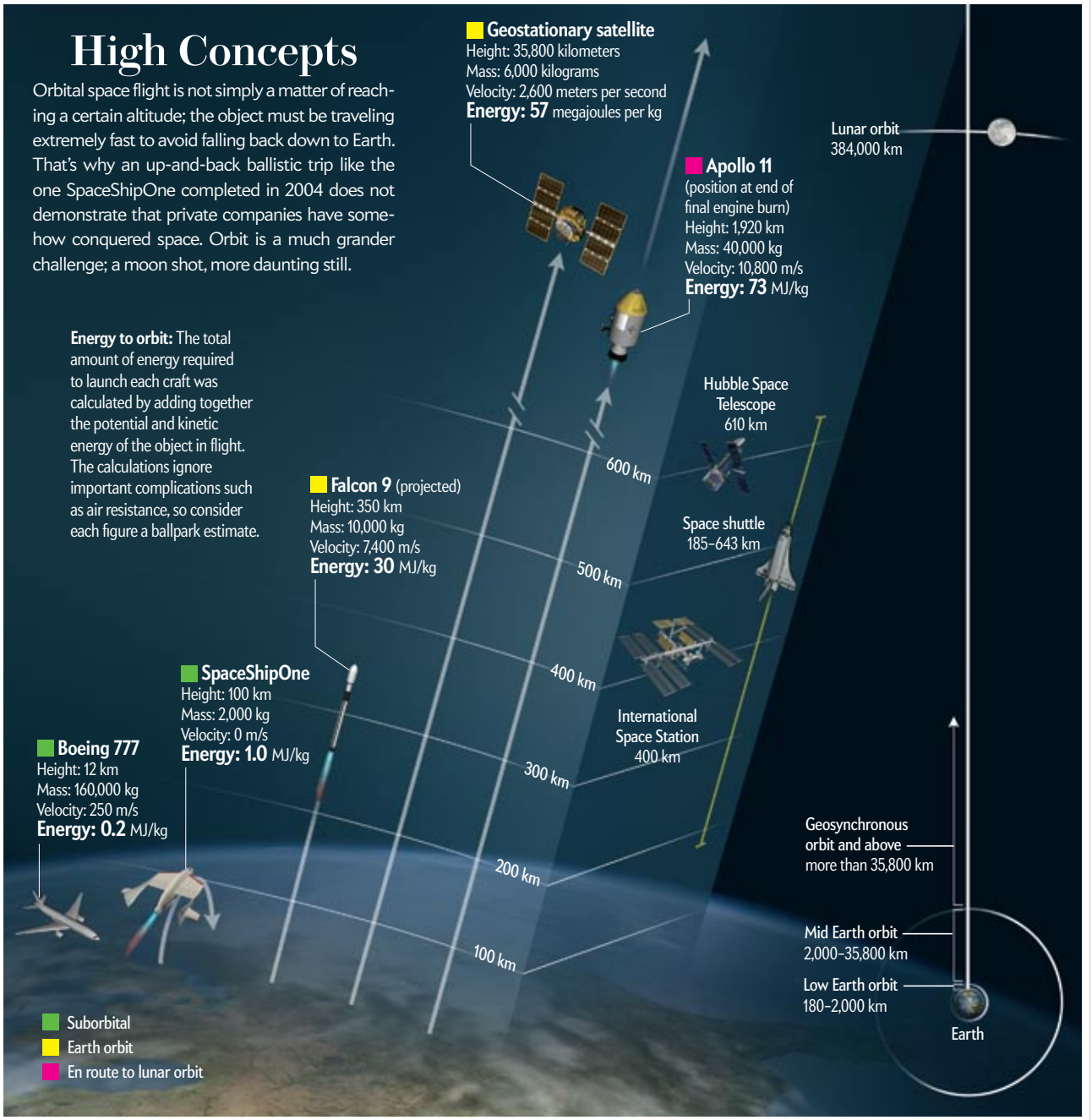
The plan is an attempt to return NASA to its 1960s glory days by making it a true research and development agency again. It would make Mars the new moon.

Cost-plus contracting drives up costs and complexity, experts agree, because as more capabilities get tacked on to the project, contractors make more money and the agency lowers its risk of someday facing charges of compromising missions with penny-pinching. And that, many say, is how NASA's human flight efforts ended up mired in low Earth orbit for nearly three decades with a billion-plus-dollar-per-flight space shuttle and, because the high costs severely limited the number of flights, not nearly enough to show for it. With Constellation, critics warned we could expect more of the same kind of waste.

A new pay-for-the-product model would not be without precedent, notes Paul Guthrie, a senior analyst at the Tauri Group, space and defense consultants in Alexandria, Va. Since World War II the U.S. government has made a point of investing heavily in industrial science and technologies with uncertain but potentially large commercial payoffs, Guthrie notes, and those sorts of investments paved the way for the biotech, computer and online industries, among others. As with the orbital-flight business today, those industries faced daunting technological and business challenges in their gestational stages but overcame them thanks to government programs that worked in much the way the new NASA plan does: by giving companies development money and serving as a guaranteed customer while the industry improves its products and develops economies of scale. The U.S. Department of Defense was the primary funder and customer of many microchip manufacturers in the early 1970s, for example, until Moore's law and increased competition yielded astounding improvements in chip capabilities and pricing.

No one knows if there's a Moore's law for space travel, but there is certainly no law that requires it to remain expensive forever. Companies competing for business under the Obama plan would be forced to find ways to save money. If they go over budget, the difference comes out of their pockets; if they come in under budget, they keep the difference. In other words, a penny saved would be a penny earned, instead of one less government penny to spend and add to the "plus."

SpaceX, the clear leader for now in the new space industry, has already been working that opportunity hard. It has cut the price tag of anodized aluminum bolts from $15 to 30 cents by machining them itself. It has slashed the cost of the carbon-based thermal material used in heat shields by coming up with its own formulation of the stuff, bypassing the industry's lone supplier. It has eliminated the need to shell out big bucks for custom-formed tapered-diameter tubing used by the space shuttle to create turbulence-free rocket engine exhaust pipes by coming up with a design that smoothes the exhaust flow using cheap, constant-diameter tubing bent into a spiral shape.



To encourage this type of innovation, NASA has to let go. The agency has always told its contractors exactly how it wants its space vehicles built, yet under the new plan NASA would simply state what it wants a finished system to be able to do, such as safely ferrying a certain amount of weight into orbit. "We won't be overly prescriptive in how we expect contractors to meet our requirements, we'll just list high-level goals and give them maximum flexibility for how to meet those goals," says Phil McAlister, a member of the NASA team in charge of program analysis. "Then at specific milestones we'll be verifying that the requirements have been met, and we'll provide whatever oversight is necessary to make sure." To help companies keep the vehicles as simple and efficient as possible, the new NASA plan also dumps Constellation's requirement that the orbital ferry be capable of continuing on to the moon. Instead the mission is just to safely and cheaply get people and cargo to the space station and back.

The elimination of the moon missions has drawn some fire, but those missions were really just dry runs for the real long-term goal of the exploration program: getting humans to Mars. And in spite of what some foes of the new plan have implied to the public, the plan does not call for NASA to spend less money on space or abandon its longer-term human space exploration plans. Rather the plan implicitly recognizes that a round-trip visit to Mars will require significant technological advances well beyond what Constellation would be likely to provide, and by freeing up NASA from having to spend all its money and expertise on orbital

Illustration by Don Foley

ferrying, the plan gives the agency the breathing room it needs to come up with those and other advances. "The plan represents a lowering of cost and better management of NASA's low-Earth-orbit business, so that it can focus on research and development, Earth science and space science," says Eligar Sadeh, president of Astroconsulting International, a space and defense consultancy in Colorado Springs, and a researcher with the U.S. Air Force Academy's Eisenhower Center for Space and Defense Studies. In fact, the plan calls for NASA budget increases over the next few years. In many ways, the plan is an attempt to return NASA to its 1960s glory days by making it a true research and development agency again, farming out the been-there work of low Earth orbit to civilian contractors. It would make Mars the new moon.

STARTING UP

THE CONTRACTOR INCENTIVES, the looser control and the resulting NASA savings would not in retrospect seem so smart if companies were to ultimately fail to deliver a safe, reliable orbital vehicle of the kind that Constellation could probably produce, if at much higher cost. Could the private sector come through? Though still too early to tell, there have been positive signs. In September 2008—just a month after the failed launch that broke up with the remains of James Doohan onboard—SpaceX's Falcon 1 became the first privately owned liquid-fuel rocket to reach orbit. It was followed less than a year later by the orbit of the Falcon 9, a more powerful rocket designed to one day carry a crew vehicle.

SpaceX's successful rocket tests are encouraging, but they are really the only hard evidence so far that private industry might succeed. The only other new player gearing up now to produce an orbital vehicle is Orbital Sciences in Dulles, Va., although at present it has little to demonstrate. Both are hiring some of the space industry's most highly regarded managers and engineers, but it is impossible to know if either company will ultimately be able to come up with a good vehicle under reduced budgets and without hordes of NASA engineers providing detailed design specs.

Nothing says they cannot do it, though, and if given a chance they probably will, says John M. Logsdon, former director of the Space Policy Institute at George Washington University. The vehicles coming out of the effort would probably end up costing less than they would have under Constellation, Logsdon adds, although they will not necessarily be that much more reliable or efficient—at least not the ones produced in the next five to 10 years. "There's likely to be some cost reduction in this first round because of reduced government oversight," he says. "But in the next round we'll see several other new players, and that may be where the real innovation comes in." Among the upstart but potentially formidable space companies said to be gearing up to compete for contracts are Blue Origin, set up by Amazon founder Jeff Bezos; Armadillo Aerospace, founded by software mogul John Carmack; and Xcor Aerospace, founded by several veterans of the rocket industry [*see box at left*].

And the industry will not just be limited to makers of orbital ferries. If lower transportation costs bring a lot more people into orbit, they are not likely to all find berths in the space station, a problem for which a solution eagerly awaits: Bigelow Aerospace in North Las Vegas has produced inflatable pods whose modular components can be transported to space and then assembled and pumped up to become orbital living quarters. Other companies are likely to emerge to provide space habitats, labs, storage and construction facilities. Yet more competition will come from governments around the world jumping into the new space race. Japan and India are already entering the fray with orbital launch capabilities.

Traditional aerospace contractors would probably compete as well for business under the Obama plan. Those giant companies can clearly build working space vehicles; the only question is whether they could build them under fixed-price rules and cost-cutting pressures. The United Launch Alliance (ULA), a joint venture of Boeing and Lockheed Martin, already launches payloads into orbit for $100 million—cheap compared with NASA launches. Although it is four times what SpaceX wants to charge, ULA has a reliability record to stand on. "When we work under fixed cost and don't have the customer looking over our shoulder reviewing every little thing we do, we can run lean, too," says Jayne Schnaars, Boeing's vice president of business development for space exploration.

THE ORBITAL ECONOMY

THE BIGGEST POTENTIAL PAYOFF to the Obama plan would be the opportunity to drive the costs of a flight to orbit down low enough to create a virtuous circle: as prices drop, more people will fly, and as more people fly, economies of scale and increased competition will lead to lower prices, and so on. The circle would be reinforced when enough people fly to justify the creation of more

NEW PLAYERS

The Next NASAs

More than 10 companies have announced their intention to launch humans into space. Astronauts could reach the International Space Station on the Taurus 2 (*1*), built by Orbital Science Corporation; SpaceX's Falcon 9 (*2*), which successfully launched earlier this summer; or on a variant of a Delta rocket (*3*), built by United Launch Alliance, a joint venture between Boeing and Lockheed Martin. Tourists could buy joyrides to suborbit on vehicles built by Xcor (*4*), Virgin Galactic (*5*), Blue Origin (*6*) or Armadillo Aerospace (*not shown*).

COURTESY OF ORBITAL SCIENCES CORPORATION (*1*); COURTESY OF SPACEX (*2*); COURTESY OF UNITED LAUNCH ALLIANCE (*3*); COURTESY OF MIKE MASSEE *Xcor* (*4*); COURTESY MARK GREENBERG *Virgin Galactic* (*5*); COURTESY OF BLUE ORIGIN (*6*)

infrastructure in orbit—that is, more places to stay and things to do—which would attract more people and lead to more infrastructure. And voilà: we'd have an orbital economy.

Would enough people line up for a ticket to make the ferries profitable and drive competition, cost-cutting and innovation? Without a clear path to real profit beyond what NASA would pay, there is no *there* there in space for the private sector. "It's possible that space could be the next Internet, giving the U.S. a long-running source of economic growth," says the Tauri Group's Guthrie. "But looming over everything is the question of how those markets will develop."

To be sure, a market already exists—the one the space shuttle has been servicing. The U.S. and many other countries will continue to be eager to send scientists and technicians to the space station to conduct zero-gravity health, biological or chemical research or to tweak equipment emplaced to observe Earth or space. (As part of the Obama plan, the life of the space station has been extended from 2015 to 2020.) If a newly competitive space industry can drive the cost of a taxi to orbit down toward $5 million, more countries will send more researchers. Still, that dramatically lower price is likely to be too high for most funding bodies. Whereas there may be dozens of takers every year, there will not be many hundreds.

The prospects for a thriving orbital economy would rise considerably if zero-gravity manufacturing looked as if it could be profitable. Today, though, the signs are not encouraging. The near absence of gravity—well, there is plenty of gravity, but objects in orbit are in free fall and don't "feel" it—enables the production of unusually large and pure crystals, perfect ball bearings and other spherical products, and perfectly heterogeneous mixtures of chemicals. Regardless of the price premium such unusual products and substances might command, the cost of setting up and operating a plant in the sky and of getting supplies up and finished products back down, would wipe out that premium thousands of times over, at least for anything discovered so far. "Even if there were an asteroid made out of diamond somewhere nearby, the cost of getting to it, mining it and bringing the pieces back probably wouldn't be justified as a business," says Lon Levin, co-founder of XM Satellite Radio and president of SkySevenVentures, a Washington, D.C., venture capital fund that invests in space-related and other start-ups.

The mere possibility that some fantastically valuable pharmaceutical or nanomaterial that can be manufactured only in microgravity could be awaiting discovery should guarantee that some orbital taxi rides will go to industrial researchers looking for those applications. "The hellacious cost of getting to orbit has been what's limited that area of experimentation," says Boeing's Schnaars. "As the cost goes down, there'll be more and more of it, and if there's enough of it there's a better chance of finding one that succeeds." It might only take one such discovery, Guthrie notes, to lead to a manufacturing operation big enough to provide a real boost to the orbital economy.

Still, most observers agree that the best bet for a potential near-term growth market is space tourism. Since 2001 Russia has flown seven tourists to the space station—one of them flew twice—via the Soyuz at prices ranging between $30 million and $50 million. At significantly lower prices, the number of takers would climb. "We have one and only one market fact, which is that the market demand for tourists to go to the space station is not zero," Levin says. "We know there is a set of people who are willing to pay between $10 million and $20 million to get there. If the price were to head down toward $1 million, might hundreds of people buy a ticket? It's possible, and that could make it a real business." A lottery approach to selling some of the seats—where, for instance, $100 buys a one-in-10,000 chance of winning a ride—could further increase sales.

Even if there were an asteroid made of diamond, the cost of setting up a plant in the sky and of getting finished products back down wouldn't be justified as a business.

Levin and other observers also point out a darker roulette wheel at play: the chance that a budding orbital-tourism industry will suffer a mishap at some point and kill one or more of its customers. Should that happen, the space tourism business would instantly evaporate, asserts Sherman McCorkle, CEO of the investment consulting firm Technology Ventures in Albuquerque—just 150 miles north of where the state of New Mexico is building a $300-million "spaceport" in anticipation of a bustling spaceflight industry. "If the seventh tourist flight to orbit fails, there's a high probability there will not be an eighth one for many, many years," McCorkle says. "Entrepreneurs are used to dealing with failure by tenaciously fixing the problems after they come up, but that won't work with space tourism the way it works with satellite communications."

On the other hand, neither risk nor catastrophe would dissuade a large segment of the potential market, argues Scott Tibbitts, founder of the eSpace Center for Space Entrepreneurship in partnership with the University of Colorado. "Society looks at the risks of adventure tourism favorably," Tibbitts says. "After eight people were killed trying to climb Mount Everest in 1996, sales of Everest expeditions to the public skyrocketed. No one talks about shutting down the skydiving business when a skydiver is killed. Tolerance for risk in space will increase, especially when prices come down to between $1 million and $5 million a seat. At those prices there could be a heck of a lot of people who want to fly as quick as a company can launch them."

Unless some alternative soon presents itself, tourism is likely to be the linchpin of the orbital economy—and for at least a few years, that could be slow-going. "It's clearly a limited market for the foreseeable future," Logsdon says. Adventure tourism for multimillionaires may seem like a superficial and fickle peg on which to hang our dreams of space exploration, but it makes a certain sense. Capitalism is the most powerful tool humanity has yet devised; the drive to push beyond our earthly home is our most ambitious project. The best way to achieve one may be to hitch a ride on the other. SA

MORE TO EXPLORE

Rocketeers: How a Visionary Band of Business Leaders, Engineers, and Pilots Is Boldly Privatizing Space. Michael Belfiore. Smithsonian, 2007.

Space Sticker Shock. George Musser in *Scientific American*, Vol. 300, No. 1, pages 22–23; January 2009.

Review of U.S. Human Spaceflight Plans Committee—Final Report. Chaired by Norman R. Augustine, October 2009. **www.nasa.gov/offices/hsf/home**

AN ANIMATED LOOK AT ORBITAL FLIGHT **www.ScientificAmerican.com/dec2010/space**

Michel M. Maharbiz is an associate professor of electrical engineering and computer sciences at the University of California, Berkeley. His lab has harnessed nature's ability to grow and power tiny flying machines, a.k.a. beetles, and melded it with computer command systems that allow researchers to direct the insects' flight.

Hirotaka Sato received his B.S. and Ph.D. in chemistry from Waseda University in Tokyo for his work on electrochemistry-based nanofabrication processes. He started his postdoctoral work on cyborg beetles in 2007 at the University of Michigan at Ann Arbor and in 2008 at Berkeley.

ROBOTICS

Cyborg Beetles

Tiny flying robots that are part machine and part insect may one day save lives in wars and disasters

By Michel M. Maharbiz and Hirotaka Sato

THE COMMON HOUSEFLY IS A MARVEL OF AERONAUTICAL engineering. One reason the fly is a master at evading the handheld swatter is that its wings beat remarkably fast—about 200 times a second. To achieve this amazing speed, the fly makes use of complex biomechanics. Its wings are not directly attached to the muscles of the thorax. Rather the fly tenses and relaxes the muscles in rhythmic cycles that cause the thorax itself to change shape. That deformation in turn sets the wings to oscillating, much the way a tuning fork vibrates after having been struck. In this way, the fly manages to convert a tiny bit of energy into a whole lot of motion with very little effort.

Engineers, spurred by the miniaturization of computer circuits and micromanufacturing techniques, have done their best to build tiny flying machines that imitate this locomotive ability. The DelFly Micro, unveiled in 2008 by researchers at the Delft University of Technology in the Netherlands, weighs only three grams, has a wingspan of 100 millimeters and can carry a tiny video camera. The synthetic flier produced at the Harvard Microrobotics Laboratory is even smaller—it weighs in at a mere 0.06 gram (still more than four times heavier than a fly)—though once set in motion, the flier's flight cannot be controlled. The real Achilles' heel of these mechanical insects, however, is the amount of power they consume: no one has yet figured out how to pack enough energy into miniature batteries to

IN BRIEF

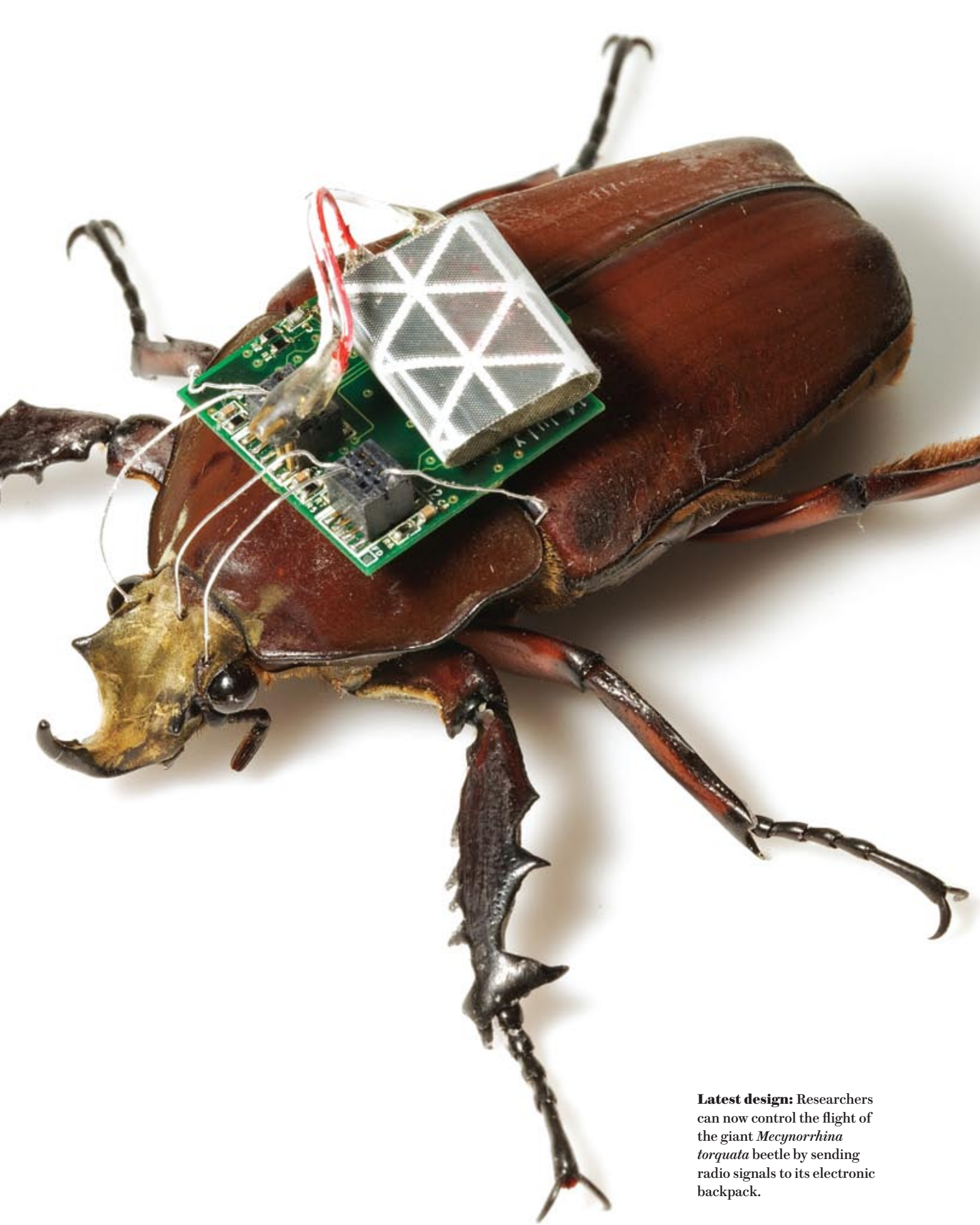
Martial need: The military would like to develop tiny robots that can fly inside caves and barricaded rooms to send back real-time intelligence about the people and weapons inside.

Technical hitch: Current fully synthetic micromechanical fliers require too much energy to be powered by today's miniature batteries for longer than a few minutes of free flight.

Potential solution: Attach a camera and other equipment onto the backs of insects, which are already incredibly energy-efficient fliers, to control where and how they fly.

Progress so far: Researchers at Berkeley, M.I.T. and Cornell have shown that they can wirelessly control a giant beetle's ability to start and stop flying, turn left or right, and fly in rough circles.

Photograph by David Liittschwager



Latest design: Researchers can now control the flight of the giant *Mecynorrhina torquata* beetle by sending radio signals to its electronic backpack.

supply the fliers with juice for more than a few minutes of flight.

In the past few years we have hit on a way around these technical limitations. Rather than building a robotic insect from scratch, we use the insects themselves as flying machines. In that way, we dispense with the heavy batteries and the micromanufacturing techniques and focus just on the man-made control systems, which intervene as necessary in the animals' flight. In other words, the insect flies itself, but circuitry embedded into its nervous system transmits commands—turn left or right, up or down—from remote human operators. In effect, we make cyborg fliers—part insect, part machine.

Our goal was to show that we could remotely induce an insect to fly, control its turns and speed when required, then stop it when the insect reached a set location—all done repeatedly and reliably.

We got the idea five years ago, when one of us (Maharbiz) attended a workshop about cyborg fliers organized by the Defense Advanced Research Projects Agency (DARPA). (I was an expert in microtechnology, but I did not know much about insects.) At the workshop, participants reviewed some of the technology that allows biologists to receive and record electrical signals from individual muscles of free-flying insects. Amit Lal, the DARPA program manager who organized the conference, thought that the time was right to build on these advances by determining if we could also transmit electrical signals to those muscles via implanted microcircuits that would make them move the way we wanted them to move.

Cyborg insects would potentially have many military uses, including the ability to tell how many people are inside a building or a cave and identify who they are before deciding whether to commit soldiers to clear the location. Silicon-carbon hybrids could also lead to civilian innovations, such as creating insectoid robots that can find survivors in the rubble of an earthquake.

WHY BEETLES?

BEFORE THE DARPA CONFERENCE, many of the best studies describing insect flight had been done in locusts, moths and flies. By piggybacking my endeavors on that work, I thought I could reduce the number of false starts that always accompany a new field of inquiry. Moths and locusts are large, but they cannot carry much weight, so they were out. That left flies.

Flies have many advantages. For one thing, biologists know a fair amount about them. Michael H. Dickinson of the California Institute of Technology and others have worked out in great detail which muscles twitch where and when to generate lift and turns in flies. Moreover, flies are incredibly efficient users of energy, which allows them to beat and steer their wings at fantastic speeds. From an engineering standpoint, however, flies are hard to work with. They are so small that you practically have to be a nanosurgeon to implant the necessary wires and circuits in them, and I'm no nanosurgeon. I started thinking about alternatives. Dragonflies were big enough and amazing fliers, but they are very fragile. Cockroaches were possibilities.

That is when I picked up a copy of *The Biology of the Coleoptera,* a classic guide to the world of beetles written by R. A. Crowson in 1981. It turns out that beetles fly much the way flies do. The flight muscles of a beetle's thorax deform its shell so that the wings oscillate like a tuning fork. The types of muscles and their positions on the beetle also seemed similar to the fly. A few elegant studies of beetles from the 1950s offered ideas on where to begin. But perhaps most important of all: beetles are large—ranging from one millimeter to more than 10 centimeters. Beetles also account for one fifth of all known species. So in theory, there was ready access. But here I encountered a new problem: few people in the U.S. raised beetles large enough for my purposes. In the end, it took years for my laboratory to develop a fairly stable supply of beetles, which we now import from breeders in Europe and Asia.

At this point in the research, the other of us (Sato), a chemist with expertise in nanofabrication, joined as a postdoctoral fellow. Our goal was to show that we could remotely induce an insect to fly, control its turns and speed when required, then stop it when the insect reached a set location. As engineers, we wanted these functions to be repeatable and reliable, with little or no damage to the insect.

We first had to decide on a minimum set of behaviors that we needed to control to produce a rudimentary cyborg flier. Because we wanted to control insects in free flight, we did not want to use tethers to maneuver their behavior as others had done—the lines would get long and tangled up. We settled on using radio control, in much the way hobbyists remotely control miniature cars, planes and helicopters. We wanted to start and stop the wingbeat on demand, increase or decrease the insect's lift in flight, and produce left and right turns. We explicitly did not want to control every aspect of the insect's flight, because the beetles are already good at leveling to the horizon and adjusting their speed and trajectories to wind and obstacles.

At the same time, we wanted to be sure we could deliver signals directly into the insect's own neuromuscular circuitry, so that even if the insect attempted to do something else, we could provide a countercommand. Any insect that could ignore our commands would make for a crummy robot.

We weren't exactly flying blind. Most of the beetles we chose to work with can each carry a load that weighs between 20 and 30 percent of its body weight. Thus, the size of the insect determines the maximum size of our control equipment. Because we knew which muscles on the beetle make the wings oscillate, it seemed reasonable to suppose that delivering electrical charges of varying frequencies to the muscles on either side of the body would allow us to change the insect's trajectory by changing the way the insect was flapping its wings.

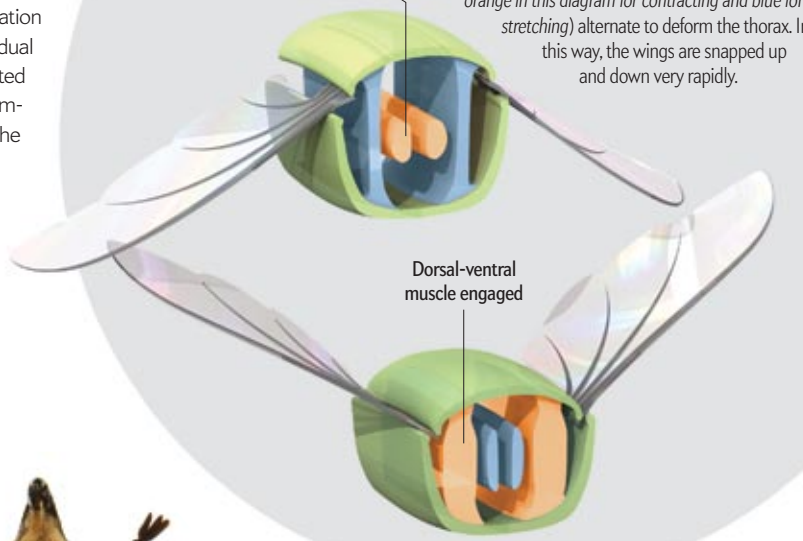
We also knew that these insects use visual cues extensively during flight. Just as in humans, light entering the insects' eyes trigger light-sensitive neurons. The signals generated by these neurons travel down the optic lobes into the midbrain and ganglia, where they are processed and provide the insect with visual information during locomotion. We also knew that the amount of light mattered in a broad sense. If, for example, we abruptly turned off the lights in a room, our beetles immediately stopped flying—implying that the insects required some sensory input from the eyes to continue oscillating their wings. We reasoned that stimulation of the optic lobes or the areas near the base of the optic lobes might elicit strong locomotion responses. Because directly implanting the eye or the optic lobe itself would impair the insect's ability to maneuver, we focused our stimula-

Flight-Control Plan

The authors use carefully timed electrical pulses to stimulate relatively large areas of insect neuromuscular circuitry to direct their beetle's flight. Had the stimulation scheme depended on the triggering of an individual neuron, the results could not have been replicated across many insects. The attachment point of the implant would have shifted in midflight, rendering the insects uncontrollable.

The Mechanics of Beetle Flight

Beetles move their wings much the way a tuning fork oscillates. Instead of pulling the wings up and down directly, two sets of muscles (*color-coded orange in this diagram for contracting and blue for stretching*) alternate to deform the thorax. In this way, the wings are snapped up and down very rapidly.



Wireless Flight Control

In much the same way hobbyists remotely maneuver miniature cars, planes and helicopters, the researchers developed a system for sending radio commands to beetles in free flight.

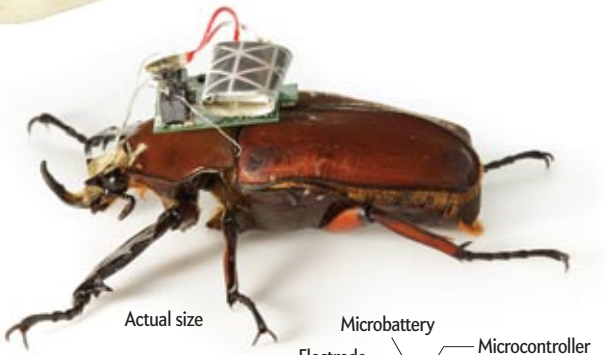
Six electrode stimulators are implanted into the beetle near the left and right optic lobes, in the brain, on the thorax (counterelectrode), and in the right and left basalar flight muscles.

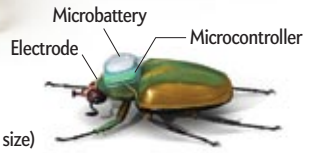
Circuit board assembly (*silver-colored battery on top*) delivers electrical pulses to the appropriate sites to make the beetle start or stop flying, turn left or right, or increase or decrease power.

1.6 cm

Antenna: A solid-state receiver relays flight commands to the attached circuit board assembly.

Mecynorrhina torquata





Cotinis texana (actual size)

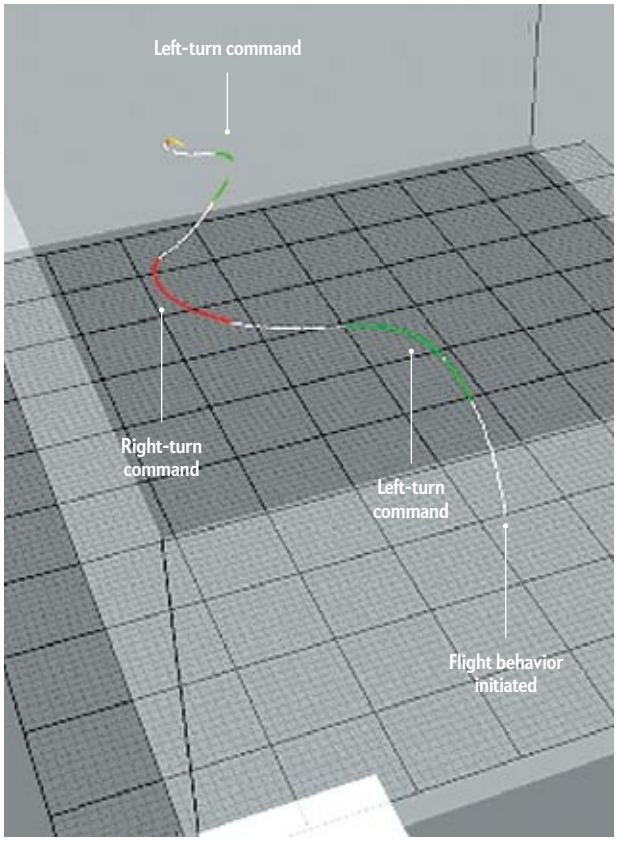
Early Experiments

Preliminary work with Texas Green June Beetles established that wing oscillations could be controlled. For this early model, flight commands were preloaded into the microcontroller. But for wireless control, a radio needed to be added to the payload—too much weight for the two-centimeter-long beetles to handle.

Illustration by Bryan Christie; photographs by David Liittschwager

Trajectory of a Cyborg

Investigators at Maharbiz's lab put cyborg beetles through their paces in a specially equipped test room (*below; Sato is standing*). The flight path depicted at the right began (*bottom right, white line*) by stimulating the beetle's optic lobes, which triggers flight behavior. Electrical pulses delivered to the right basalar muscle prompt the insect to turn to the left, and stimulating the left basalar muscle results in right turns. The flight ended (*top left*) after the optic lobes received a second pulse longer than the first one.



tion instead on the areas at the base of the lobes. We did not have to stimulate individual neurons. Rather if we delivered the correct electric pulse near the base of the optic lobes, the beetle's own circuitry took care of the rest, and the beetle took flight.

IF AT FIRST YOU DON'T SUCCEED

WE HAD MANY FALSE STARTS before making our first successful flight. Initially we worked for six months with *Zophobas morio* beetles (1.5 centimeters long and weighing one gram), also known as darkling beetles. These insects are available at pet stores because their larvae are used to feed pet geckos and other small reptiles. Unfortunately, we never could figure out how to get them to fly. We threw them in the air hundreds of times, and they simply refused to open their wings. Apparently *Zophobas* just does not seem to like to fly much. (We certainly learned a lot of insect anatomy from *Zophobas,* though.) Eventually we switched to the Texas Green June beetle, *Cotinis texana* (two centimeters long, weighing one to 1.5 grams), which is common in the southeastern U.S. and is popularly referred to as a June bug.

We did not want to repeat our experience with *Zophobas,* so we looked for a beetle that flies, and *Cotinis* is a well-known flier—as well as a pest to fruit farmers. In fact, for a couple of years we collected thousands of these from farmers who could not believe we were paying them five dollars per beetle to get rid of their pests.

Based on these early experiments with *Zophobas* and *Cotinis,* we figured out exactly how to hold the beetles without hurting them and where to glue the microwires on the back near the wing muscles and at the base of the head. (We used beeswax.) We designed and custom-built tiny circuit boards that could receive radio instructions and apply the types of electrical signals with which we were experimenting. (For examples of beetles outfitted with both an early version of the technology and our latest—as of April—iteration, see the box on the preceding page.) Nowadays the basic system consists of the following components: a microcontroller with a built-in radio (to receive instructions), a battery (to deliver electric charges), and several thin (125-micron diameter) silver wires implanted into the brain and the flight muscles.

Because the Texas beetles could at most carry between 200 to 450 milligrams of payload, the initial system was not equipped with a radio. To test the control, we would preload flight commands into the microcontroller and then observe the beetle

SOURCE FOR TELEMETRY DATA: SVETOSLAV KOLEV AND NIMBUS GOEHAUSEN *University of California, Berkeley*

Photograph by David Liittschwager

whether it was free-flying, tied to a string or suspended inside of a gimbal. (Attaching a beetle to a gimbal allows us to watch it fly in place.)

Our first success with *Cotinis* took two months to achieve. After several experiments, we found a relatively large section of neurons that, when electrically stimulated, could produce repeatable and predictable modulations of flight. We determined that stimulating an area of the insect brain that lies just between the left and right optic lobes with fast electrical pulses (around 10 milliseconds long, or 100 hertz) causes the insect to start beating its wings and adopt a correct flight posture almost every time (97 percent of the time, to be exact). Equally exciting, one longer pulse to the same area stopped the wing oscillation completely. In other words, we could toggle the insect on and off—applying a pulse to start its wings going and another pulse to get it to stop.

We believe this longer pulse effectively overloads the neurons at the base of the optic lobe and prevents any electrical signals from propagating. This activity, in turn, disrupts the trigger signal that maintains wing oscillation [see "More to Explore" on this page for video links of this and other behaviors]. We found that our electrical impulses worked, over and over, regardless of what the insect happened to be doing at the time. If a beetle was walking along a table when we started the 10-millisecond electrical pulses, its wings started beating and it flew off. If we placed it on its back on the table and gave it a pulse, it would beat its wings upside down. If it was already in flight and we gave it an additional pulse, its wings would stop and it would fall—and then continue crawling.

There was no indication that we were damaging the insects—even when they fell to the floor. Implanted beetles lived for just as long as nonimplanted beetles (a few months). They flew, ate and mated just like regular beetles. We further found that when applying "on" and "off" signals repeatedly and in quick succession while the insect was flying, we could modulate the wing oscillations. That is, once the insect was flying, if we quickly issued the on and off commands one after the other, the oscillation of the wings would not cease but would merely dampen slightly. This had the effect of changing the insect's thrust and of allowing us to reliably control the power the beetles used to fly, much the way pilots use a throttle to control their planes.

To make the beetles turn, we implanted microwires on the right and left basalar muscles. By applying 10-millsecond pulses to the right muscle, the insect would produce more power on the right side, causing it to veer left (movies are available online at www.eecs.berkeley.edu/~maharbiz/Cyborg.html and at www.frontiersin.org/integrative_neuroscience/10.3389/neuro.07/024.2009/abstract). Eventually we started using *Mecynorrhina torquata* beetles, which at eight grams are ideal for carrying both the radio and the payloads that we have developed.

NEXT STEPS

AS EYE-CATCHING AS some of these results are, we need to do more. Although we have shown that we can make a beetle turn left and right and fly in rough circles, we ultimately want to be able to guide a beetle's flight through complex three-dimensional patterns so that they can fly around obstacles—down chimneys and up pipes, for example. To do this, we have added to the payload tiny microphones that record the wingbeats of the beetle in flight. When the sound reaches a certain level—broadly indicating whether the wing is up or down in its beat—we can apply precise stimulation pulses to the steering muscles of the beetle.

The hardware is now working pretty well, but we would like some help with the computer code that controls our beetles. We have reached out to some of our colleagues who have more experience with programming the software for fully synthetic fliers. Based on his work with autonomous helicopters, Pieter Abbeel of the University of California, Berkeley, along with his students Svetoslav Kolev and Nimbus Goehausen, is developing a control system for insects that breaks down complex commands (such as "change heading by 20 degrees") to their component parts (such as "apply 10-millsecond pulses to the left basalar muscle for so many seconds"). A user would then only have to enter certain course corrections, and the microcontroller would handle the specific stimuli needed to make the beetle fly in that direction. To figure out what that series of stimuli needs to be, we are using magnetic resonance imaging scans, extensive anatomical investigations and high-speed recordings of flying beetles to map out the three-dimensional configuration and function of some of the other muscles responsible for steering each wing. From these data, we are now targeting different muscles so that we might control yaw and roll more independently in free flight.

SHOULD WE MAKE CYBORG BEETLES?

WHETHER OR NOT remotely controlled insects will be useful as robots is an open question, but our hunch is that they will be. Smaller and lower-power microcontrollers and radios will continue to appear on the market, allowing us to develop better and finer control of our cyborg beetles. As long as it remains difficult to develop miniature power sources that pack a huge wallop or engineer highly energy-efficient mechanical wings, our beetles and their superefficient muscles will enjoy a distinct advantage over entirely synthetic fliers.

Of all the implications our work might have, we believe this to be the most fundamental: as our computational technology gets smaller and our knowledge of the biological systems advances, we will be increasingly tempted to introduce synthetic interfaces and control loops into existing biological systems. Working out the details in insects first will help us avoid mistakes and false starts in higher organisms, such as rats, mice and ultimately people. And it allows us to postpone many of the deeper ethical questions about free will, among other things, that would become more pressing if this work took place on vertebrates. Developing cyborg beetles will not replace the fundamental pursuit of building synthetic robots (given that humans often build better machines than nature does), but the discipline of seamlessly merging the organic with the synthetic is only beginning. SA

MORE TO EXPLORE

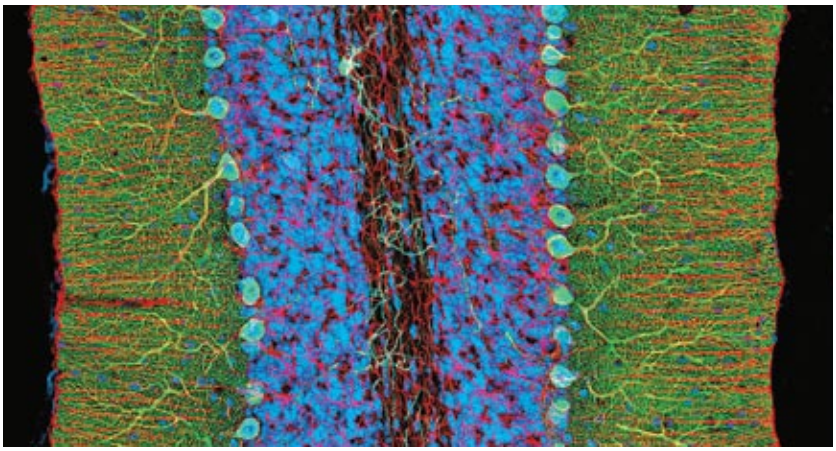
A Radiotelemetric 2-Channel Unit for Transmission of Muscle Potentials during Free Flight of the Desert Locust, *Schistocerca gregaria*. H. Fischer, H. Kautz and W. Kutsch in *Journal of Neuroscience Methods*, Vol. 64, No. 1, pages 39–45; January 1996.

Wing Rotation and the Aerodynamic Basis of Insect Flight. Michael H. Dickinson, Fritz-Olaf Lehmann and Sanjay P. Sane in *Science,* Vol. 284, pages 1954–960; June 18, 1999.

A Dual-Channel FM Transmitter for Acquisition of Flight Muscle Activities from the Freely Flying Hawkmoth, *Agrius convolvuli*. N. Ando, I. Shimoyama and R. Kanzaki in *Journal of Neuroscience Methods,* Vol. 115, No. 2, pages 181–187; April 2002.

Remote Radio Control of Insect Flight. H. Sato, C. W. Berry, Y. Peeri, E. Baghoomian, B. E. Casey, G. Lavella, J. M. VandenBrooks, J. F. Harrison and M. M. Maharbiz in *Frontiers in Integrative Neuroscience,* Vol. 3, Article 24; October 5, 2009.

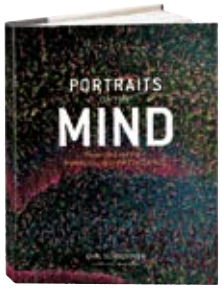
SEE CYBORG BEETLES FLY www.ScientificAmerican.com/dec2010/cyborg_video



COURTESY OF THOMAS DEERINCK AND MARK ELLISMAN, 2004

Portraits of the Mind: Visualizing the Brain from Antiquity to the 21st Century

by Carl Schoonover. Abrams, 2010 ($35)



Get inside the head with this exploration of the brain and the techniques neuroscientists use to study it. Essays from leading scientists and Carl Schoonover's detailed captions provide context for the many stunning images—from the quiet pen-and-ink drawings of individual neurons by Santiago Ramón y Cajal, the father of modern neuroscience, to psychedelic pictures of tissues such as the cerebellar tissue shown above, colored using a technique called antibody staining.

Bird Songs Bible: The Complete, Illustrated Reference for North American Birds, edited by Les Beletsky. Chronicle Books, 2010 ($125). See and hear nearly 750 birds in this richly illustrated volume—which includes a digital audio player loaded with bird songs and calls—produced with the Cornell Lab of Ornithology.

The Atlas of the Real World: Mapping the Way We Live, by Daniel Dorling, Mark Newman and Anna Barford. Revised and expanded from the 2008 edition. Thames & Hudson, 2010 ($34.95). Cocktail-party conversation fodder abounds in this book, which maps everything from carbon dioxide emissions to atheism.

Origins: Human Evolution Revealed, by Douglas Palmer. Mitchell/Beazley, 2010 ($34.99). Hobbits, Neandertals and australopithecines are just a few of the extended family members you will meet in this book featuring reconstructions by paleoartist John Gurche.

The World of Trees, by Hugh Johnson. University of California Press, 2010 ($34.95). Trees around the globe—from silver firs to southern beeches, mulberries to maples—get their due in this spectacular guide.

Come See the Earth Turn: The Story of Léon Foucault, by Lori Mortensen. Tricycle Press, 2010 ($17.99). Aimed at children aged seven to nine, this book—elegantly illustrated by Raúl Allén—recounts Foucault's pendulum experiment, which proved that the earth turns on its axis.

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/dec2010

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SCIENTIFIC AMERICAN MARKETPLACE

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). He is author of *Why People Believe Weird Things* and blogs at BigQuestionsOnline.com.

The Conspiracy Theory Detector

How to tell the difference between true and false conspiracy theories

This past September 23 a Canadian 9/11 "truther" confronted me after a talk I gave at the University of Lethbridge. He turned out to be a professor there who had one of his students filming the "confrontation." By early the next morning the video was online, complete with music, graphics, cutaways and edits apparently intended to make me appear deceptive (search YouTube for "Michael Shermer, Anthony J. Hall"). "You, sir, are not skeptical on that subject—you are gullible," Hall raged. "We can see that the official conspiracy theory is discredited.... It is very clear that the official story is a disgrace, and people who go along with it like you and who mix it in with this whole Martian/alien thing is discrediting and a shame and a disgrace to the economy and to the university" [sic]. Hall teaches globalization studies and believes that 9/11 is just one in a long line of conspiratorial actions by those in power to suppress liberties and control the world.

Conspiracy theories are a dollar a dozen. While in Calgary on that same trip, I met a politician who told me that he believes the fluoridation of water is the greatest scam ever perpetrated on the public. Others have regaled me for hours with their breathless tales of who really killed JFK, RFK, MLK, Jr., Jimmy Hoffa and Princess Diana, along with the nefarious goings on of the Federal Reserve, the New World Order, the Trilateral Commission, the Council on Foreign Relations, Yale University's secret society Skull and Bones, the Knights Templar, the Freemasons, the Illuminati, the Bilderberg Group, the Rothschilds, the Rockefellers and the Learned Elders of Zion. It would take Madison Square Garden to hold them all for a world-domination meeting.

Nevertheless, we cannot just dismiss all such theories out of hand, because real conspiracies do sometimes happen. Instead we should look for signs that indicate a conspiracy theory is likely to be untrue. The more that it manifests the following characteristics, the less probable that the theory is grounded in reality:

1. Proof of the conspiracy supposedly emerges from a pattern of "connecting the dots" between events that need not be causally connected. When no evidence supports these connections except the allegation of the conspiracy or when the evidence fits equally well to other causal connections—or to randomness—the conspiracy theory is likely to be false.
2. The agents behind the pattern of the conspiracy would need nearly superhuman power to pull it off. People are usually not nearly so powerful as we think they are.
3. The conspiracy is complex, and its successful completion demands a large number of elements.
4. Similarly, the conspiracy involves large numbers of people who would all need to keep silent about their secrets. The more people involved, the less realistic it becomes.
5. The conspiracy encompasses a grand ambition for control over a nation, economy or political system. If it suggests world domination, the theory is even less likely to be true.
6. The conspiracy theory ratchets up from small events that might be true to much larger, much less probable events.
7. The conspiracy theory assigns portentous, sinister meanings to what are most likely innocuous, insignificant events.
8. The theory tends to commingle facts and speculations without distinguishing between the two and without assigning degrees of probability or of factuality.
9. The theorist is indiscriminately suspicious of all government agencies or private groups, which suggests an inability to nuance differences between true and false conspiracies.
10. The conspiracy theorist refuses to consider alternative explanations, rejecting all disconfirming evidence and blatantly seeking only confirmatory evidence to support what he or she has a priori determined to be the truth.

The fact that politicians sometimes lie or that corporations occasionally cheat does not mean that every event is the result of a tortuous conspiracy. Most of the time stuff just happens, and our brains connect the dots into meaningful patterns.

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/dec2010

Illustration by Emiliano Ponzi

There is one aspect of life that ***unites***, ***controls***, and ***affects*** all people. That one aspect of life is the collection of ***natural laws***. They ***unite***, ***control***, and ***affect*** human life no matter what people's race, gender, or creed or where on this planet they live. Consider that ***whoever or whatever*** created the laws of physics also created another law to ***unite***, ***control***, and ***affect*** people's relationships with one another.

Richard W. Wetherill
1906-1989

The problem being addressed here relates to the fact that people unknowingly ***unite*** against one another and seek a kind of ***control*** that ***affects*** not only their health and well-being but culminates in death.

If you are a new reader of this subject matter, be prepared for a pleasant shock.

Whoever or whatever is the creator revealed ***nature's law of right action*** to the mind of Richard W. Wetherill in 1929. The law calls for people to be ***rational*** and ***honest*** not only regarding the laws of physics but also to be ***rational*** and ***honest*** in their thinking and behavior toward one another.

After decades of rejection, the behavioral law is as viable and effective as when created, whereas people's behavior, in general, has been becoming more and more blatantly irrational and dishonest.

Despite the fact that compliance to every law of physics requires its specific right action to succeed, people's behavior toward one another, whether noble or ignoble, was deemed to be a matter of personal choice.

Wetherill used words to describe the elements of nature's law of behavior such as rational, logical, honest, appropriate, moral, and true to the facts, and he also cautioned that the law, itself, is the final arbiter of what is ***right behavior***. The formula states: ***Right action gets right results whether it relates to laws of physics or the law of behavior, whereas wrong results in either case indicate failure properly to comply.***

There is one requirement of the behavioral law that people need to give careful attention. Rational and honest responses in their relationships with one another must be made specifically to ***satisfy the law*** and not to satisfy their particular expectations.

Ordinarily people conduct their relationships to satisfy their purposes, none of which qualify according to natural law. Such behavior, however, does explain why the earth's population is not being peacefully ***united***, ***controlled***, nor favorably ***affected***.

Do people intentionally refuse to accommodate the requirements of gravity for instance? No, they do their best to keep their balance or recover it when needed.

Behavioral responses require that same attitude. Do not act for personal reasons; act because a self-enforcing natural law requires people's ***obedience***.

Those who are familiar with the accounts of creation in scriptures will realize that the first wrong act of the created beings was to ***disobey***. That wrong behavior ended the perfect situation that had existed, and it brought about the predicted wrong results.

Whether those accounts are actual or symbolic, they illustrate the problem.

For ages whoever or whatever is the creator allowed people to control their behavior and suffer the resulting troublesome problems but also created a natural law of behavior that when identified and obeyed unites people, allowing them to enjoy the benefits that then control and affect their lives.

Visit our colorful Website www.alphapub.com where several natural-law essays and seven books describe the changes called for by whoever or whatever created nature's behavioral law. The material can be read, downloaded, and/or printed FREE.

This public-service message is from a self-financed, nonprofit group of former students of Mr. Wetherill. Please help by directing others to our Website. For more information write to: The Alpha Publishing House, PO Box 255, Royersford, PA 19468.

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column for 100 years, within an order of magnitude. He also hosts the *Scientific American* podcast Science Talk.

Fatuous Fantasies

When it comes to counting calories, a mind is a terrible thing to your waist

Yiddish literature includes numerous stories about the mythical village of Chelm, filled with people who, well, let's put it this way: they are not likely to graduate first in their Yeshiva class. One such tale involves befuddled carpenters who could not figure out why, no matter how many times they cut additional pieces off the ends of a board, it was still too short. Oy.

Now new research shows that when it comes to food, most people are honorary citizens of Chelm. Investigator Alexander Chernev, for one, has discovered that many people believe they can cut a meal's calorie count by an ingenious method—adding more food! Oy.

Chernev, who investigates consumer behavior at Northwestern University's Kellogg (snap, crackle, pop) School of Management, spends an inordinate amount of time around hamburgers for a guy who's not managing a McDonald's. Publishing in the *Journal of Consumer Psychology,* he explains that people act as if healthful foods have "halos"—their healthfulness extends to the rest of the meal. Vegetables and fruit: big halos. Angel food cake: no halo. Go figure.

Here is where the mind applies cockamamie calculus to meals. Eaters consider a food's healthfulness to be related to how "fattening" it is. "Because healthier meals are perceived to be less likely to promote weight gain," Chernev writes, "people erroneously assume that adding a healthy item to a meal decreases its potential to promote weight gain." More is less, more or less.

He had more than 900 subjects look at four different meals and estimate their calorie contents. The meals were a hamburger, a bacon-and-cheese waffle sandwich, chili with beef and a meatball-pepperoni cheesesteak—none of which are going to win any prizes from the American Heart Association, and all of which sound really good right now.

(I just remembered there's leftover pizza in the fridge. Back in a mo.)

Where were we? Right, bad foods, bad. Half of the participants were also shown an obviously healthful side dish, such as three sticks of celery. Of course, the only real reason for anyone to want three celery sticks is to make an "A" that Hester Prynne could have worn on the planet Krypton or to do a surprisingly good impression of a walrus leading an orchestra. But I digress while I digest.

The subjects who saw only the main meal guessed it had, on average, 691 calories. Subjects who saw the same meal served with the perfunctory celery sticks or other healthful window dressings guessed that the entire meal had just 648 calories. That's 43 fewer calories, which a really imaginative person could then add to the burger-and-celery-meal with, say, a cookie to get the calorie count back up to the burger by itself.

This kind of fatatouille reasoning was on display in a study that Cornell University's Brian Wansink, a leader in eating-behavior research, presented at the Association for Consumer Research conference this past October. He found that people who ate at restaurants that claimed to be healthy estimated a meal's calorie count to be only 56 percent of its true number. Individuals making this big error then compounded it by figuring their assumed low-cal meal made it okay to have more of the bad stuff, such as fries or cookies. That kind of logic will go straight to your hips.

Back to Chernev. His truly devilish discovery, which he dubs the "dieter's paradox," is that the strength of the belief about adding good foods to fight bad ones correlates with concern over putting on pounds: the people who worry most about their weight thought that, on average, the burger-plus-veggie combo had 96 fewer calories than the burger alone. The folks who were not anxious about adipose still fell for the halo-induced paradox, but they thought the veggies cut only 26 calories off the meal.

For public health advocates, the takeout or, rather, take-home message is that merely promoting the consumption of healthful foods may actually be calorie counterproductive. Because an apple a day keeps the paradox in play. SA

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Illustration by Matt Collins

Amazing New Hybrid Runs Without Gas

The new face of time? Stauer's Compendium Hybrid fuses form and functionality for UNDER $50! Read on...

Innovation is the path to the future. Stauer takes that seriously. That's why we developed the ***Compendium Hybrid***, a stunningly-designed hybrid chronograph with over one dozen analog and digital functions that is more versatile than any watch that we have ever engineered.

New technology usually starts out at astronomical prices and then comes down years later. We skipped that step to allow everyone the chance to experience this watch's brilliant fusion of technology and style. We originally priced the Stauer ***Compendium Hybrid*** at $395 based on the market for advanced sports watches... but then stopped ourselves. Since this is no ordinary economy, we decided to start at 88% off from day one. That means this new technological marvel can be yours for only $49!

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The watch's extraordinary dial seamlessly blends an analog watch face with a stylish digital display. Three super-bright luminous hands keep time along the inner dial, while a trio of circular LCD windows track the hour, minutes and seconds. An eye-catching digital semi-circle animates in time with the second hand and shows the day of the week. The watch also features a rotating bezel, stopwatch and alarm functions and blue, electro-luminescence backlight. The ***Compendium Hybrid*** secures with a rugged stainless steel band and is water-resistant to 3 ATMs.

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December 1960

Evolution and Behavior

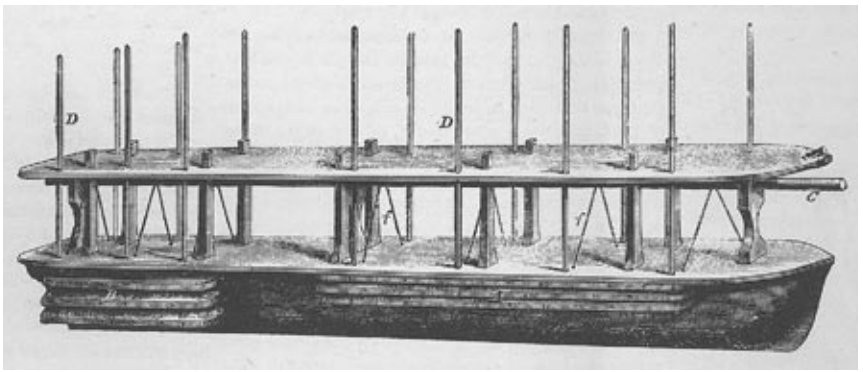
"Gulls live in flocks. They forage together the year around and nest together in the breeding season. No external force or agency compels them to this behavior; they assemble and stay together in flocks because they respond to one another. Their gregarious and often co-operative behavior is effected through communication. Each individual exhibits a considerable repertory of distinct calls, postures, movements and displays of color that elicit appropriate responses from other members of its species. Since the differences among these closely related birds are not induced by the environment, but are truly innate, it was clear that the present differences among the species must have arisen through evolutionary divergence. —N. Tinbergen"

NOTE: *Nikolaas Tinbergen shared a Nobel Prize in 1973 for his work on social behavior in animals. This article is available in full on the Web at www.ScientificAmerican.com/dec2010*

December 1910

Undersea World

"Sir John Murray, the distinguished oceanographer who recently visited the United States, remarked in an address made a few years ago before the British Association for the Advancement of Science, that 'the deep sea discoveries of the past quarter of a century have been the most important additions to the natural knowledge of this planet since the great voyages of Columbus and Magellan.' When attention is called to the fact that great reefs and islands have been formed through the activity of small coral animals, we have but a single instance of the importance of zoological studies in the deep seas. To-day hundreds of naturalists are working on the materials and data collected by Agassiz, the Prince of Monaco, and other deep-sea explorers."



Abraham Lincoln's invention for buoying vessels over sandbars, 1860

Information Thaw

"The Russian government has hitherto found it impossible to keep in touch with Kamschatka during two-thirds of the year, owing to the severe winter storms. Now, however, by the aid of wireless telegraphy, this region may be kept in communication with the rest of the world all the year round. A series of stations has been established, and special inducements are offered to operators who will take charge of these isolated points."

December 1860

Honest Abe's Patent

"In discharging our accustomed round of duties at the Patent Office recently, our attention was called to a model of a patented mode of buoying vessels, the invention of no less a personage than the President elect of the United States. Thinking it would interest a vast number of our readers to see what sort of an invention emanated from the brain of so distinguished an official, we had an ambrotype taken from the model [*see illustration*]. It is probable that among our readers there are thousands of mechanics who would devise a better apparatus for buoying steamboats over bars, but how many of them would be able to compete successfully for the presidency?"

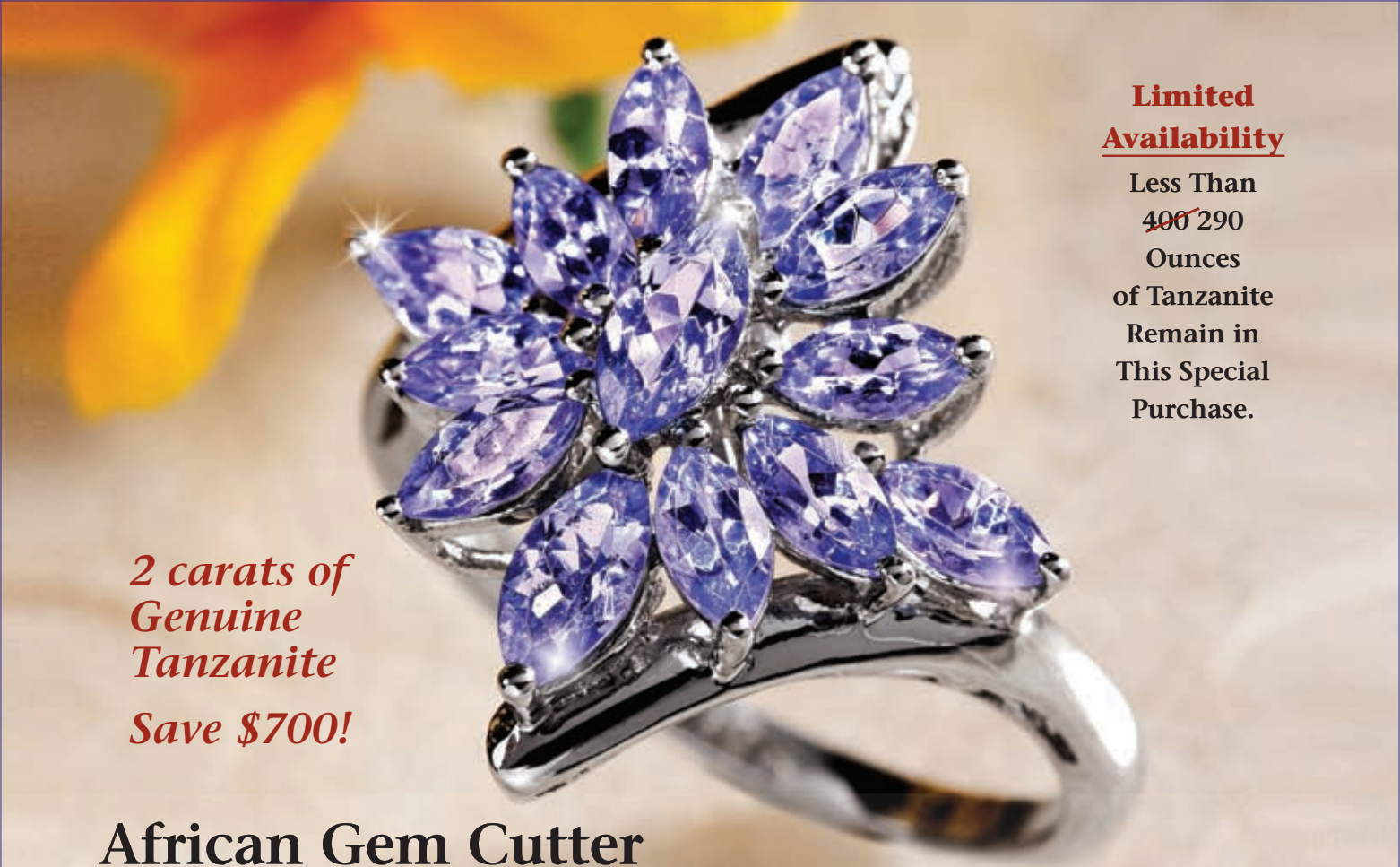
Evils of Absinthe

"A new stimulant has been coming into pernicious prevalence among artists and literary men of France. This is absinthine, the bitter principle of wormwood, which is soluble in alcoholic liquors. Several distinguished men in France are said to have fallen victims to its use, and the highest medical authorities in that country have denounced it. We hope it may never come into use as a stimulant among our people. He who persists in it ultimately becomes a driveller and a paralytic. Science in its very highest sense teaches us that cravings of the appetite for stimulants in human beings should, in general, be resisted."

Wonders of Coca

"The decoction of the leaves of the coca—a Peruvian Erythroxylon shrub—recently introduced into Europe, is exciting attention as possessing a peculiar stimulating power. These leaves chewed in moderate doses of from four to six grains excite the nervous system, and enable those who use them to make great muscular exertion, and to resist the effect of an unhealthy climate, imparting a sense of cheerfulness and happiness. The Indians of Bolivia and Peru travel four days at a time without taking food, their only provision consisting in a little bag of coca. What a chance this is for a patent medicine man!" SA

SCIENTIFIC AMERICAN, VOL. III, NO. 23, DECEMBER 1, 1860



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African Gem Cutter Makes $2,689,000 Mistake...Will You?

This story breaks my heart every time. Allegedly, just two years after the discovery of tanzanite in 1967, a Maasai tribesman knocked on the door of a gem cutter's office in Nairobi. The Maasai had brought along an enormous chunk of tanzanite and he was looking to sell. His asking price? Fifty dollars. But the gem cutter was suspicious and assumed that a stone so large could only be glass. The cutter told the tribesman, no thanks, and sent him on his way. Huge mistake. It turns out that the gem was genuine and would have easily dwarfed the world's largest cut tanzanite at the time. Based on common pricing, that "chunk" could have been worth close to $3,000,000!

The tanzanite gem cutter missed his chance to hit the jeweler's jackpot...and make history. Would you have made the same mistake then? Will you make it today?

In the decades since its discovery, tanzanite has become one of the world's most coveted gemstones. Found in only one remote place on Earth (in Tanzania's Merelani Hills, in the shadow of Mount Kilimanjaro), the precious purple stone is 1,000 times rarer than diamonds. Luxury retailers have been quick to sound the alarm, warning that supplies of tanzanite will not last forever. And in this case, they're right. Once the last purple gem is pulled from the Earth, that's it. No more tanzanite. Most believe that we only have a few years supply left, which is why it's so amazing for us to offer this incredible price break. Some retailers along Fifth Avenue are more than happy to charge you outrageous prices for this rarity. Not Stauer. Staying true to our contrarian nature, we've decided to ***lower the price of one of the world's rarest and most popular gemstones.***

Our 2-Carat ***Sunburst Tanzanite Ring*** features marquise-cut gems set dramatically in gorgeous sterling silver. Each facet sparkles with the distinct violet-blue hue of the precious stones. Behind the shine you'll find that the exquisite silverwork of the setting calls to mind the detailed treasures being produced by Europe's finest jewelers. This is a ring designed to impress and it does not disappoint.

Now is the point where opportunity knocks. If you open that door today, you can own this spectacular ring for less than $100. If you wait? We can't say for sure.

Your satisfaction is completely guaranteed. For our client-friendly approach, Stauer has earned a rare **A+ rating from the Better Business Bureau**, a rating we wish to keep. So, of course, your satisfaction is 100% guaranteed. If you are not completely aglow with the ***Sunburst Tanzanite Ring***, send it back within 30 days for a prompt and courteous refund. But, please don't wait, our supply is dropping rapidly.

JEWELRY SPECS:

– 2 ctw genuine tanzanite – .925 sterling silver setting – Ring sizes 5–10

Sunburst Genuine Tanzanite Ring (2 ctw)—~~$795~~

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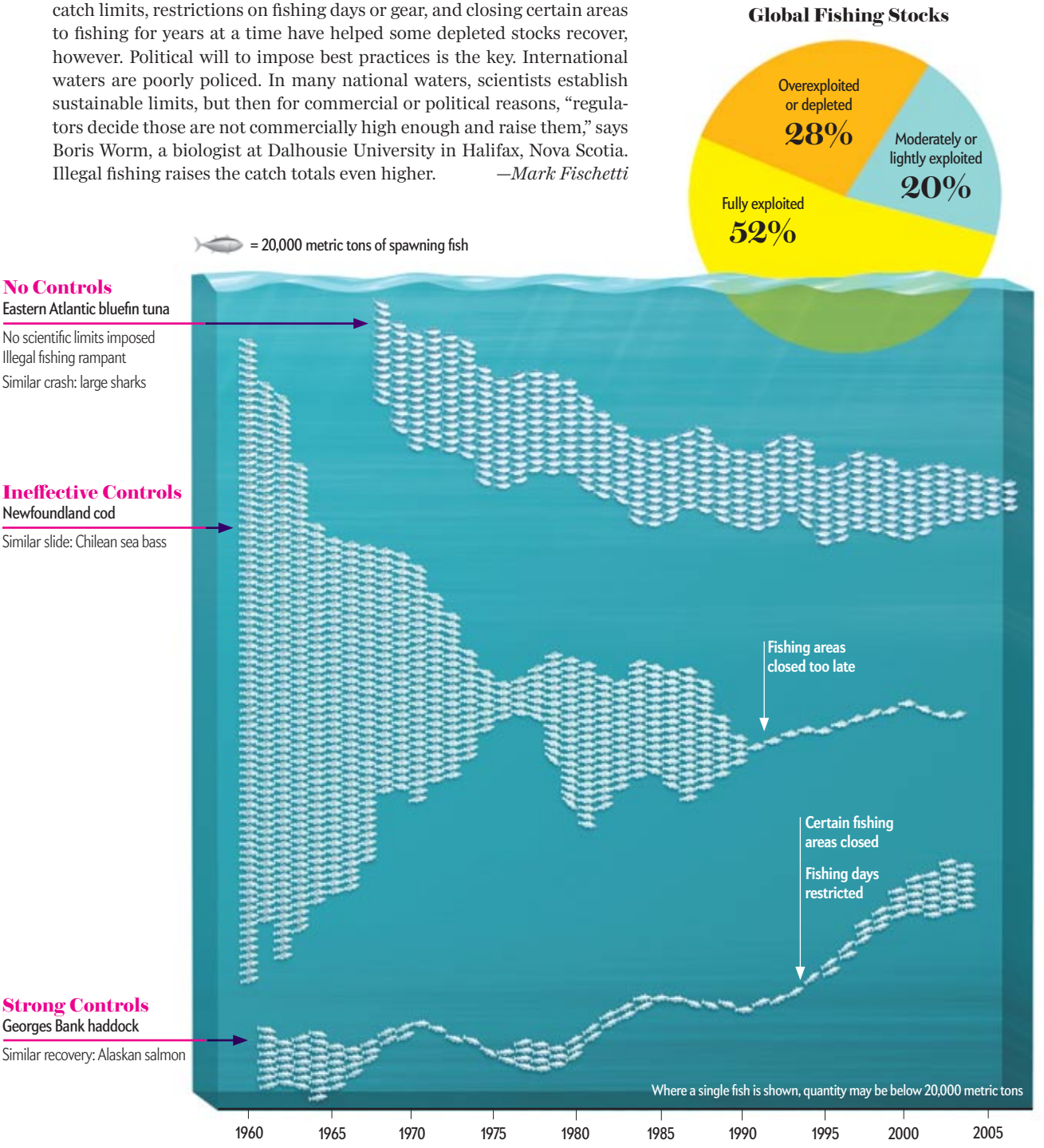
Silent Seas

The world's fisheries continue to collapse, although smart controls could help

We are emptying the oceans of fish faster than most species can repopulate themselves. Proven management practices such as conservative catch limits, restrictions on fishing days or gear, and closing certain areas to fishing for years at a time have helped some depleted stocks recover, however. Political will to impose best practices is the key. International waters are poorly policed. In many national waters, scientists establish sustainable limits, but then for commercial or political reasons, "regulators decide those are not commercially high enough and raise them," says Boris Worm, a biologist at Dalhousie University in Halifax, Nova Scotia. Illegal fishing raises the catch totals even higher. *—Mark Fischetti*



SOURCES: FOOD AND AGRICULTURE ORGANIZATION (*metrics for fishing stocks*); WOODS HOLE NATIONAL MARINE FISHERIES SERVICE AND DALHOUSIE UNIVERSITY (*fish in sea*)

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/dec2010

Graphic by George Retseck

Nature has something to tell you.

Thanks. The more efficient a system, the less fuel it uses and the better it is for the environment. ENERGY STAR®-qualified York Affinity™ Furnaces have an off-the-charts efficiency rating up to 98%.* As a matter of fact, the York Affinity Modulating Furnace is the most efficient gas-fired residential furnace on the market today. Rather than simply switching on or off, it works like a dimmer switch–evenly replacing the amount of heat leaving the home and automatically adjusting itself to maintain the desired temperature setting. Quiet, eco-friendly Affinity systems save energy, money, and the planet. Now that feels nice. Call your York Dealer at 800-910-YORK to learn more. Visit us online at yorkupg.com/comfort.

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