SCIENTIFIC AMERICAN

February 2011 ScientificAmerican.com

Spacecraft
Do-It-Yourself Satellites

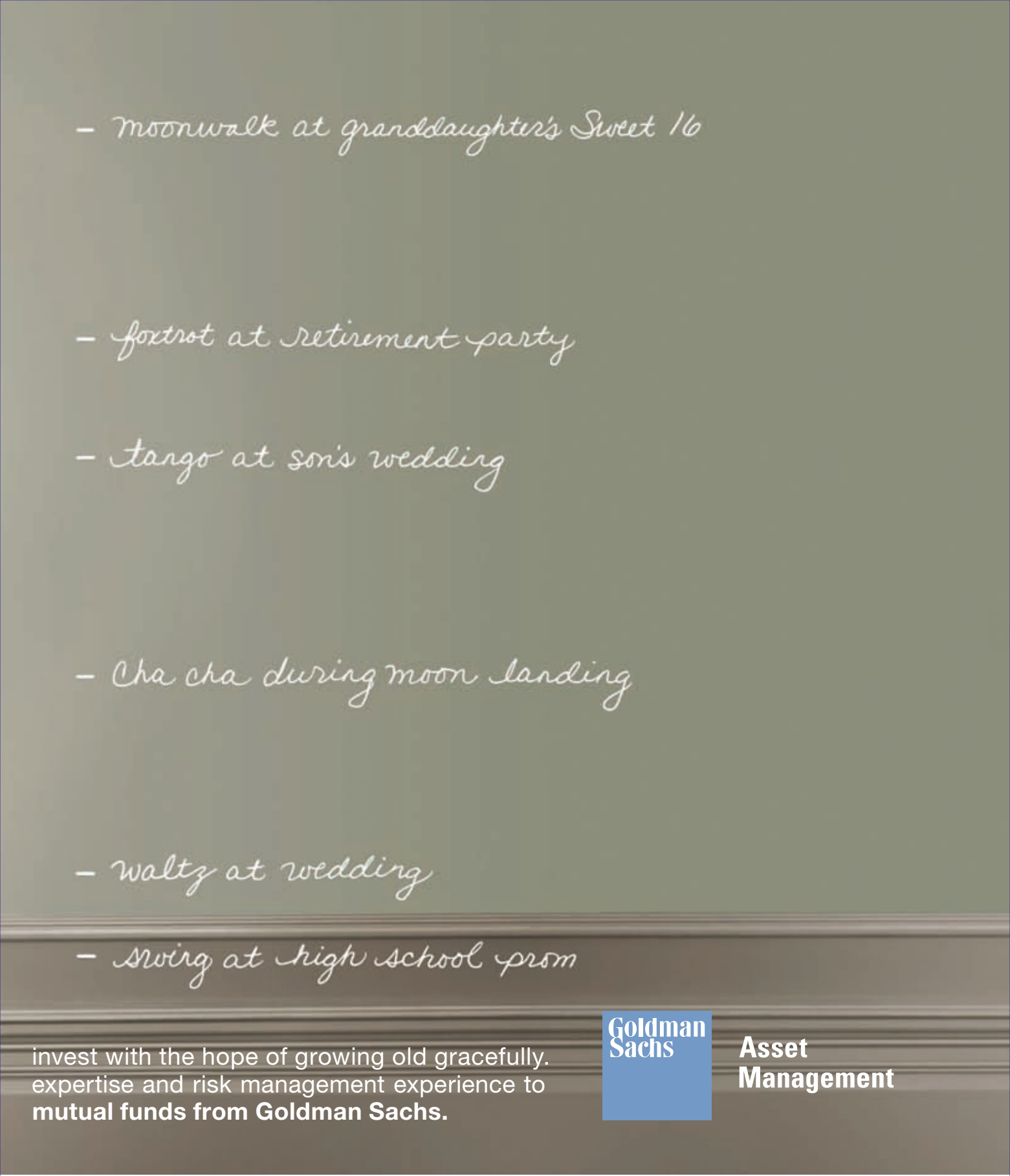
Brain Science
How Language Shapes Thought

Fish Farms
A Blue Food Revolution?

Scaling Back Obesity

What science says about losing weight and keeping it off PAGE 40

Summary prospectuses, if available, or prospectuses for the Funds containing objectives, risks, charges and expenses, and read the summary prospectus prospectus contain this and other information about the Fund. ***gsam.com***



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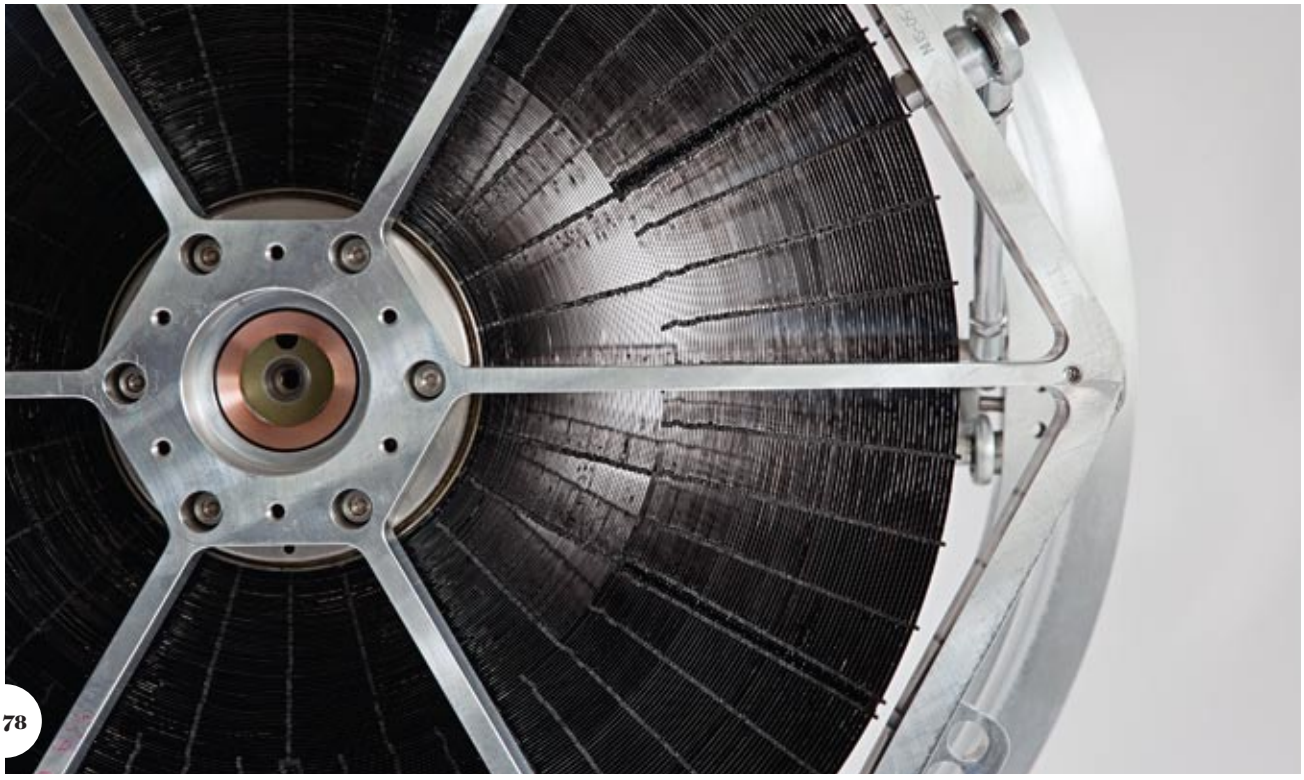
February 2011 Volume 304, Number 2

ON THE COVER

If current trends continue, an excess of weight will surpass smoking as the primary cause of preventable deaths in the U.S. Health experts, however, often overlook the best near-term strategy for stopping the obesity epidemic: behavior-modification methods that have been shown to change people's eating and exercise habits.
Illustration by Bryan Christie.



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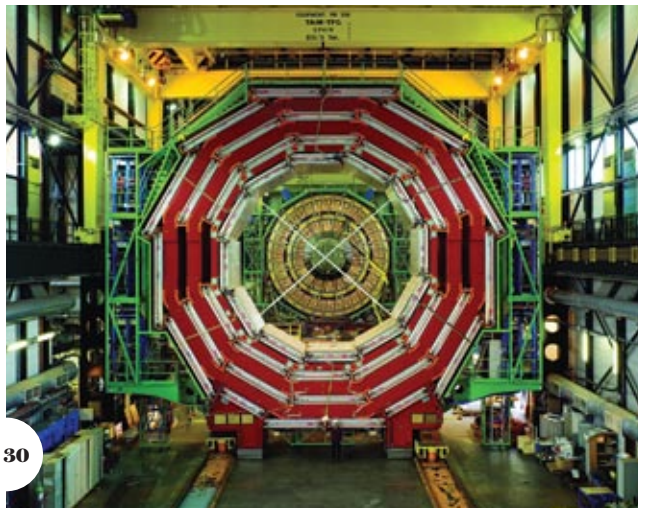

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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

On the Scene at CES 2011
Geek out with our coverage of the gargantuan tech expo, which descends every year on Las Vegas with the latest in computing and gadgetry.
Go to www.ScientificAmerican.com/feb2011/ces

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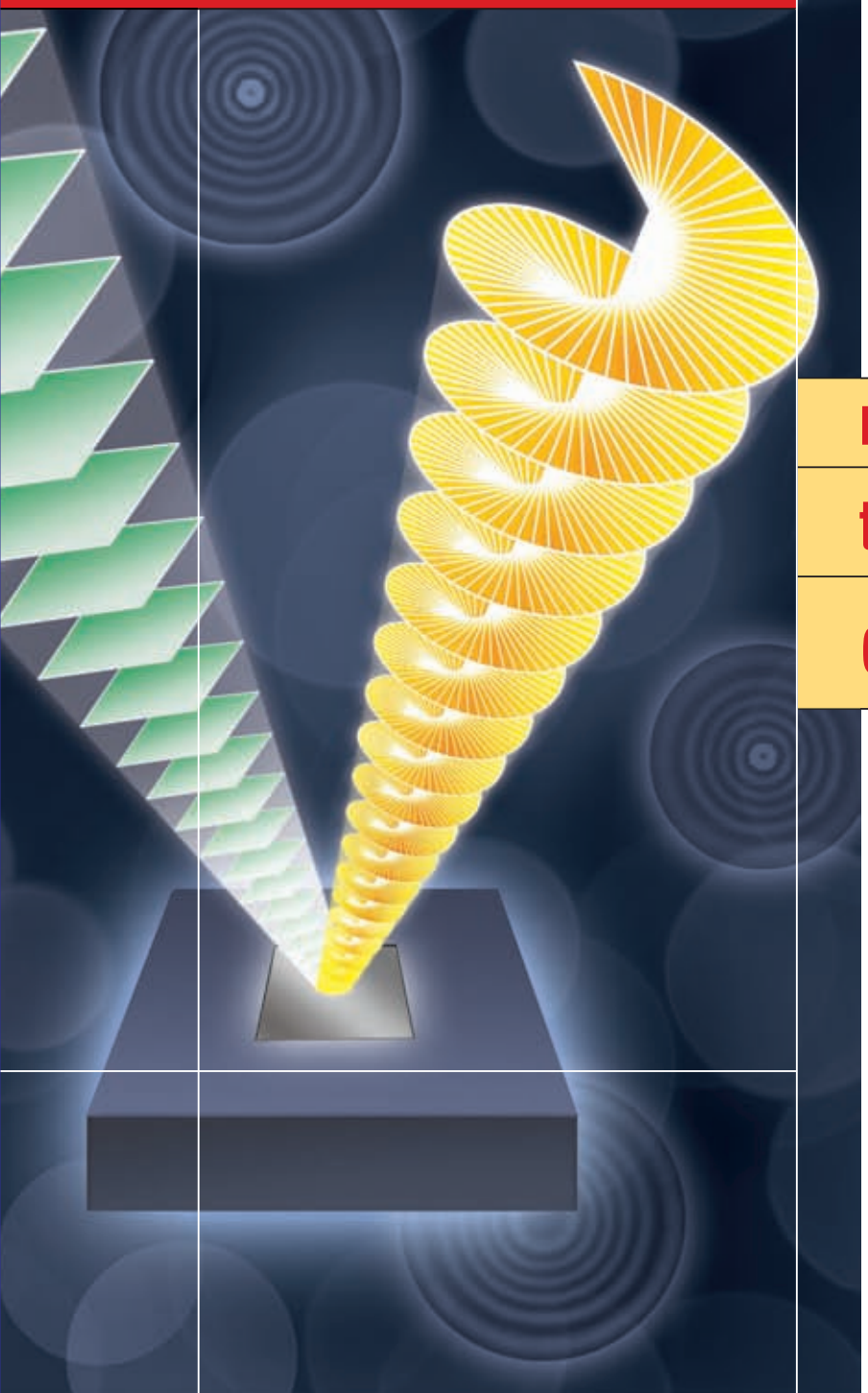
Now there's an easier way to put a precise spin on "twisted light"



Hamamatsu's computer-controlled Liquid Crystal on Silicon Spatial Light Modulator (LCOS-SLM) is able to very precisely convert a straight beam of light into a twisted, helix-shaped beam for use in many advanced applications.

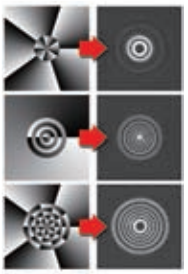
Advancing twisted light applications

Usually we think of light as traveling in a straight path, in a train of parallel planes called *wavefronts*.

But light can also be twisted into helix-shaped wavefronts for many useful new applications.

The challenge is how to *precisely control* the twisting of the light—*and* do that with equipment that is flexible and widely usable.

Hamamatsu created an elegantly simple solution...



Special phase profiles (left) twist light into the beam patterns at right.

Their *Liquid Crystal on Silicon Spatial Light Modulator* (LCOS-SLM) uses a computer to precisely shape the reflective profile of a liquid crystal surface. Applying special phase profiles to that surface will twist the reflected light in precisely controllable ways. Yet the system is compact, cost-efficient and easy to use.

Hamamatsu's LCOS Spatial Light Modulator

Which may help scientists in developing new twisted light applications...

Such as new computers that employ the infinite quantum states of optical vortices to process data. Or new generations of quantum communications and data encryption. Or "optical tweezers" that can manipulate cells and other micro particles...

Twisted light: It's another exciting new frontier that Hamamatsu is helping to open!

http://jp.hamamatsu.com/en/rd/publication/

Hamamatsu is opening the new frontiers of Light

HAMAMATSU

PHOTON IS OUR BUSINESS

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

Too Much and Not Enough

The growing familiarity of the statistics does little to ease the painful realization of how disturbing they are. About a third of Americans are overweight, and another third are obese—a jump from just 13 percent obese in 1962—and as a nation we are growing fatter all the time. The excess weight has severe consequences. It causes more than 160,000 additional deaths in the U.S. annually and exacts a financial toll: health care for a person who is 70 pounds or more overweight can cost an additional $30,000 over a lifetime. Many other countries, in both the industrial and developing worlds, are seeing similar trends.

At the same time, in a crowded and environmentally stressed world—with global population rising from 6.9 billion today to an estimated 9.3 billion in 2050—humanity is going to need to find sustainable sources of protein and nutrients.

In this edition, two feature articles take on the issues surrounding these very disparate food challenges. Our cover story, "How to Fix the Obesity Crisis," by David H. Freedman, explains the complex web of factors—social, environmental, genetic and economic—that led us to this situation. Someday science may find a pharmaceutical answer to weight gain. But until then, we have only the currently available solutions that are best supported by research. What they are may surprise you. Turn to page 40.

New app for the iPad features stories about "Origins and Endings."

Fish farms, as now practiced along coastlines, have had a controversial role in satisfying our hunger for seafood, given their track record of problematic environmental practices. With many wild fisheries collapsing from commercial overharvesting and the continuing difficulties of sustainably raising livestock such as cows, pigs and chickens on land, however, we need better answers. Could new offshore fish farms—assuming they can function efficiently—be a productive direction to explore? Contributing editor Sarah Simpson's report takes a look at that question. See "The Blue Food Revolution," which starts on page 54.

Changing topics, I'd like to update you on two items that I mentioned in my letter last issue. We have now introduced an app for the iPhone, called *Scientific American* Advances; we plan other mobile versions later this year. And by the time you see this issue, our first app for the iPad will be available for download. Called "Origins and Endings," it tells compelling stories about the cosmos, life and human innovations through feature articles, videos, interactive informational graphics, audio and slide shows from our archives. And as always, we are eager to receive your feedback. SA

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Illustration by Nick Higgins

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October 2010

BROADER BROADBAND

"Competition and the Internet" [Science Agenda] is overly simplistic when it argues that broadband in the U.S. is too expensive and too slow.

Today's most advanced applications typically require seven megabits per second of bandwidth or less, far below the capabilities of most U.S. wireline broadband. This is presumably why a recent Federal Communications Commission survey found that 91 percent of U.S. broadband users were "very" or "somewhat" satisfied with their speeds, and another study found that consumers were not willing to pay much for extra speed. Indeed, consumers in most countries typically subscribe to slower speeds than the highest available. Also, although very high speed connections in the U.S. are quite expensive relative to many developed countries, prices for slower connections compare favorably.

But most important, your editorial focuses entirely on wirelines, although wireless broadband is booming and already affects Internet use, innovation and investment. If fostering competition is the real policy objective, wireless broadband—not net neutrality—has the real potential to enhance competition, especially at slower speeds. Fostering wireless growth is far more important than getting a 100-Mbps connection in every home.

Scott Wallsten
Vice president for research, Technology Policy Institute, Washington, D.C.

"No research exists yet on the low-temperature raises caused by cell phone radiation."

Benjamin L. Viglianti
University of Michigan at Ann Arbor

SPECTRUM OF CHOICES

As parents of a four-year-old who was diagnosed to be on the autism spectrum (the subject of Nancy Shute's "Desperate for an Autism Cure") at 15 months of age, we have spent countless hours researching, measuring, experimenting and hoping for something, anything really, that could improve our son's quality of life. Our search began with conventional medicine, and we frankly hoped it would end there. But the stark reality is that conventional medicine has offered no answers at all and has seemingly been more concerned with vilifying treatments that do not require pharmaceutical intervention.

Gary Latham
Columbia, Md.

ENERGY DENSITY

Antonio Regalado's "Reinventing the Leaf" primarily discusses Caltech's Nathan S. Lewis's solar energy process, in which water is the base fuel, but there is no mention of water sources. Does the water have to be clean? Is the technology aimed specifically at water-rich places? Or if water desalination is necessary, is the project still worthwhile?

Dov Rhodes
Haifa, Israel

LEWIS REPLIES: The water does have to be clean, but in fact we hardly use any. It is not used for cooling but as the precursor to store the energy in the split forms of hydrogen and oxygen. And it takes a very small amount of hydrogen to store an enormous amount of energy—more than 100 times as much as in a lithium battery of the same weight. Also, the water would be recycled and could come from rainwater or, in many cases, even water vapor.

So water is not really an issue. Demonstrating the technology and getting it to work are much more pressing concerns for us at this stage.

INCOME GAP

In "Closing the Health Gap" [The Science of Health], Christine Gorman is exactly on target about the need for primary care except for one glaring omission: medical specialists will typically earn at least three times as much as primary care physicians in return for having spent two or three additional years of training. Until this income gap is resolved, the probability of significant numbers of physicians choosing primary care as a specialty is very small indeed.

David S. Grauman, M.D.
Fairbanks, Alaska

MICROWAVE HEAT

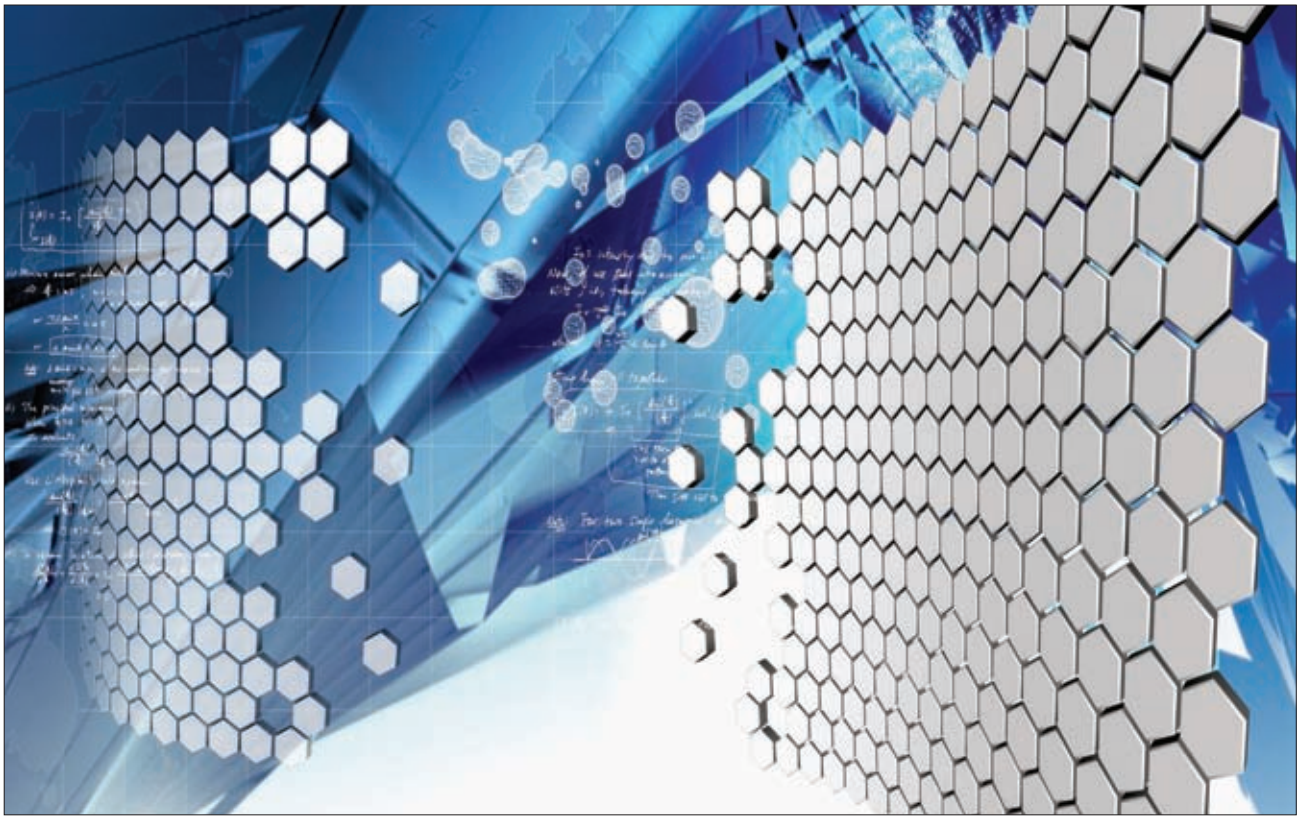
In "Can You Hear Me Now?" [Skeptic], Michael Shermer argues correctly that cell phones cannot directly break DNA. But he is wrong to assert that cancer only arises after such damage occurs or that cell phones cannot damage DNA otherwise.

A Tufts University study has found that electrical properties of one type of cell can induce other, distant cells to change their behavior. Twelve different European laboratories working as part of a European Union–sponsored project have found evidence of DNA damage from signals from modern 3G phones. Split samples of human sperm studied in six different national laboratories indicate poorer morphology, motility and increased pathology for cell phone–exposed samples. Other studies in Sweden have found that those who started using cell phones as teenagers have four to five times more brain cancer as adults.

Shermer claims that the latest WHO epidemiological studies suggest no overall increased risk in brain cancer tied with cell phone use. But this project is continuing because its leaders understand the need for continued surveillance.

Devra Davis
Department of Epidemiology
University of Pittsburgh

Shermer's point was that there is not enough energy in microwaves produced by cell phones to cause the breakage of DNA, which can lead to cancer. Although this is true, one cannot conclude that cell phones are not carcinogenic. Research does exist—



Chaos Made Clear

It has been called the third great revolution of 20th-century physics, after relativity and quantum theory. But how can something called chaos theory help you understand an *orderly* world? What practical things might it be good for? What, in fact, is chaos theory? **Chaos** takes you to the heart of chaos theory as it is understood today. Your guide is Cornell University Professor Steven Strogatz, author of *Nonlinear Dynamics and Chaos,* the most widely used chaos theory textbook in America. In 24 thought-provoking lectures, he introduces you to a fascinating discipline that has more to do with your everyday life than you may realize.

Chaos theory—the science of systems whose behavior is sensitive to small changes in their initial conditions—affects nearly every field of human endeavor, from astronomy to business. Professor Strogatz shows you the importance of this field and how it has helped us solve life's mysteries. You learn how chaos theory was discovered and investigate ideas such as the butterfly effect, iterated maps, and fractals. You also discover practical applications of chaos in areas like encryption, medicine, and space mission design.

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Chaos

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14. The Properties of Fractals
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16. Fractals Around Us
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I am a co-author on a review article relating to it—discussing the carcinogenic effect of elevated tissue temperature with and without coexisting DNA damage from other causes. To my knowledge, no research exists yet on the low-temperature rises that cell phone radiation causes, the increased neurological sensitivity of young individuals, or the unlikely situation where there is known carcinogenic exposure combined with thermal exposure below thermal levels that can cause damage. Consequently, I am hesitant in this case to completely ignore the precautionary principle.

Benjamin L. Viglianti
Department of Radiology
University of Michigan at Ann Arbor

SHERMER REPLIES [for more on this debate, see www.ScientificAmerican.com/feb2011/skeptic]: Many readers noted that cancer has many causes, such as epigenetic mechanisms that do not require the breaking of DNA chemical bonds, but these other causes are not what most critics are claiming for the alleged connection between cell phone use and brain cancer. Davis agrees with me that "cell phones cannot directly break DNA," but then she contradicts herself by citing an E.U.-sponsored study on whether DNA damage is linked to 3G phones. The E.U. study has been discredited. The other studies she mentions are either irrelevant or have not been replicated. Viglianti makes a good point that should, in principle, be a testable hypothesis that could lead to a fuller understanding of cancer and its causes. In the meantime, I cannot help but wonder why no one seems concerned about skin cancers caused by holding cell phones in one's hand and pressed against one's ear.

ERRATA

"Desperate for an Autism Cure," by Nancy Shute, indicated that methylmercury was used as a preservative in certain vaccines. Ethylmercury was used, not methylmercury. The half-life of ethylmercury is much shorter, and the human body excretes it.

Because of an editing error, Andrew Gelman's "When Small Numbers Lead to Big Errors" [Advances] stated that 0.1 percent of the U.S. population "owns guns for self-defense." It should have said "uses guns for self-defense during a typical year."

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LETTERS TO THE EDITOR

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at ScientificAmerican.com/feb2011

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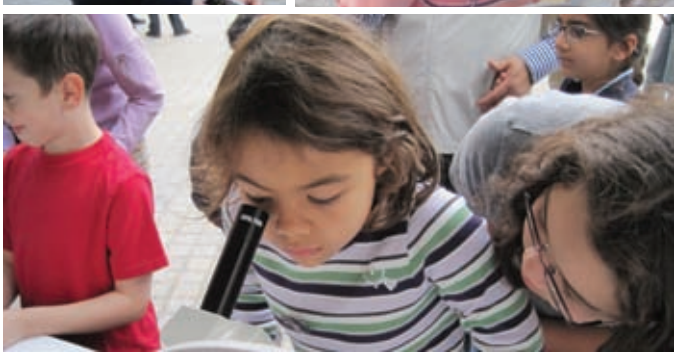
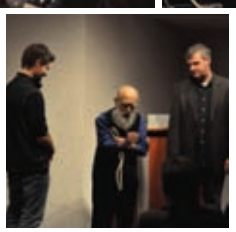
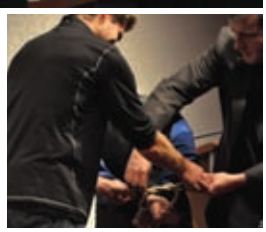


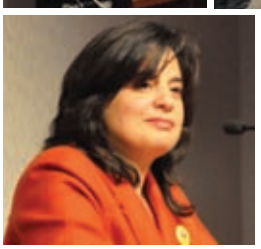
USA Science and Engineering Festival

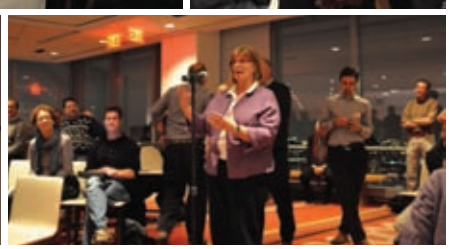
National Mall | Washington D.C. | October 23-24, 2010

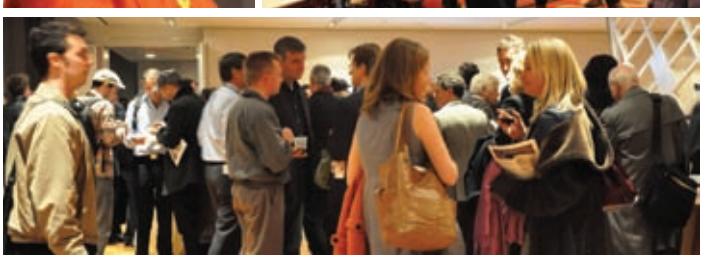
SCIENTIFIC AMERICAN was proud to be a media sponsor for the inaugural USA Science and Engineering Festival. SA's booth at the two-day Expo encouraged kids and their parents to learn about photosynthesis and find out whether algae could generate biomass fuel.











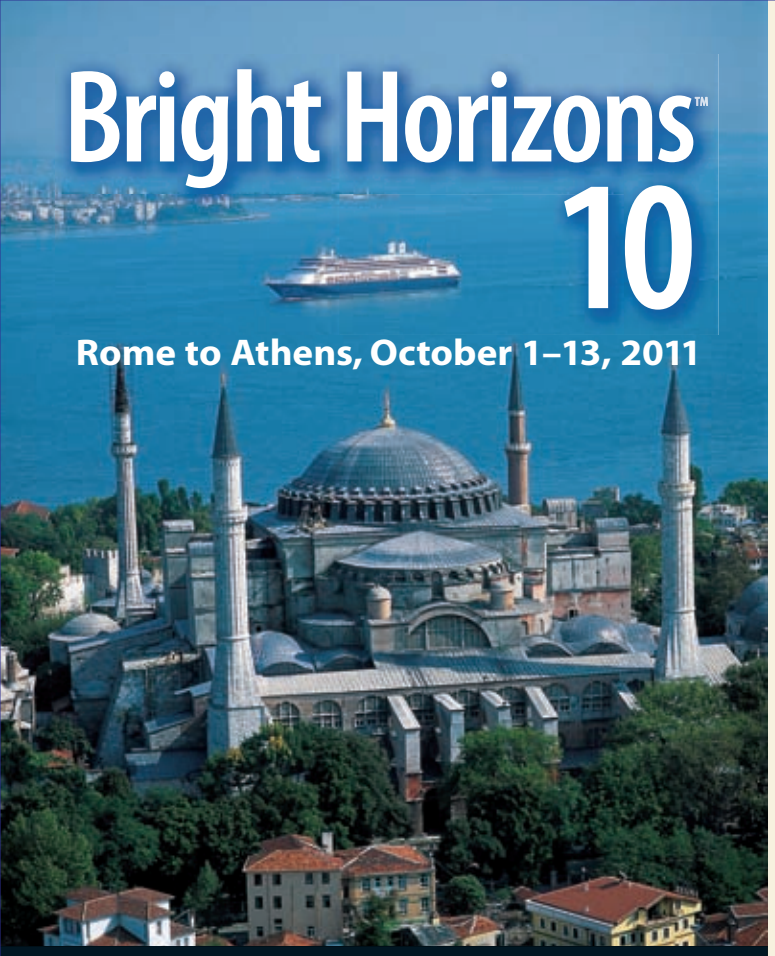
Mind Over Magic

NY Academy of Sciences | New York City | November 18, 2010

Mariette DiChristina presented Scientific American MIND authors Stephen Macknick and Susana Martinez-Conde who spoke to a sold-out crowd about the neuroscience of magic. World-renowned magician, The Amazing Randi, illustrated some of the cognitive tricks.

Bright Horizons™ 10

Rome to Athens, October 1–13, 2011



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COSMOLOGY

Speaker: **Lawrence Krauss, Ph.D.**

Quantum Man: Richard Feynman's Life in Science — It took a man who was willing to break all the rules to tame a theory that breaks all the rules. Learn about the scientific legacy of one of the greatest and most colorful scientists of the 20th century, and in turn get insights into the questions driving the science of the 21st century.

An Atom from Greece — Every atom in your body was once inside a star that exploded. Lawrence Krauss will present the life history of an atom in a glass of wine you will have with dinner, from the beginning of the universe to the end. The story is rich in drama and surprises, and will leave you thinking differently about your place in the cosmos.

The Dark Side of the Universe: From Black Holes, to Dark Matter, and Dark Energy — The most interesting things in the universe apparently cannot be seen. Learn why scientists are fascinated by them, and why they hold the key to understanding our origins, and our future.

Hiding in the Mirror: Extra Dimensions, CERN, and the Universe — The largest machine humans have ever built has turned on in Geneva, and happily has not created a black hole that destroyed the world. But what might be discovered there, and will it tell us that there is, literally, infinitely more to the universe than meets the eye?

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PALEONTOLOGY

Speaker: **Michael J. Benton, Ph.D.**

The Life and Times of the Dinosaurs — Many people think images of dinosaurs in museums and films are largely imaginary. Find out how paleobiologists reconstruct the life of the past using a combination of three modern scientific methods. Dr. Benton will share the standard tools, unexpected finds, and new engineering approach to understanding how these ancient giants looked, moved, and fed, putting dinosaur discoveries and imagery in a new light.

Origins and Extinctions — Life has existed on Earth for four billion years, punctuated by origins and extinctions. From the origin of life to the origin of humans we'll look at one of the grandest questions in science: where did we come from . . . and can we be sure? Dr. Benton then explores international research from North America, Russia, China, and Europe on the causes and consequences of extinctions.

Origins of Modern Biodiversity — Life today is hugely diverse. Darwin wondered at this richness, and argued that life was more diverse than it had to be! Research efforts now concentrate on reconstructing the evolutionary 'tree of life' using genomes and fossils, bound by massive computing power. Get the scoop on biodiversity and the latest on biogeographic investigations, fossil data, and number crunching of the new genomic sequences.

The Dinosaurs of Eastern Europe and the Mediterranean — In the days of the dinosaurs, continental drift and sea level change led to ever-changing geography. See how geologists create paleogeographic maps to locate the dinosaur fauna of what is now Eastern Europe. Meet colorful characters from early days of paleontology. Learn how regional research changed during the Iron Curtain days and how current researchers are bringing Europe's unique dinosaurs back to life.

SCIENTIFIC AMERICAN TRAVEL

BRIGHT HORIZONS

VATICAN OBSERVATORY

When in Rome, do as the Romans who are astronomy buffs wish they could do—visit to the new digs of the Vatican Observatory and get a privileged look at its world-class meteorite collection.

Join Bright Horizons on an optional pre-cruise trip to Castel Gandolfo, Italy on a private insider's tour of the Observatory's laboratory, home to a 135 kg collection of 1081 samples, from 469 meteor falls. See a bit of Mars on your Mediterranean trip! Perhaps almost more intriguing is the Observatory's library. We'll browse over the shoulders of giants, seeing historic and antique astronomy books including early editions of Newton, Copernicus, Galileo, Kepler, Brahe, Clavius, and Secchi. VO astronomers will brief us on the Vatican's interest in astronomy and the latest on VO research at Steward Observatory, Mount Graham, Arizona.

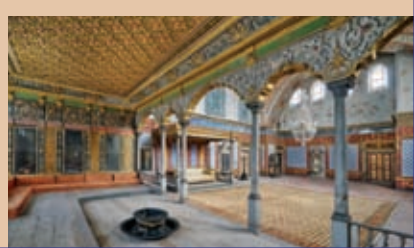
We'll lunch on the shores of Lake Albano, an extinct volcano, and linger to enjoy the scenic and historic nature of the Castel Gandolfo area before returning to the bustle of Rome.

ISTANBUL TOUR

It's impossible to describe, and has mesmerized travelers for millennia. Layered, amalgamated, flowing. Ancient and modern, secular and sacred. Plunge into Istanbul's cultural whirlwind with Bright Horizons staff, who have been there, done that.

On your itinerary: Hagia Sophia. It was the largest cathedral in the world for a thousand years, then a mosque, now a secular museum (so Istanbul). The Blue Mosque is defined by its 20,000 Iznik tiles. We'll peruse the sweets, spices, and nuts at the Spice Bazaar (A little hazelnut-pomegranate nougat, perhaps?).

Onward to our learning lab in Turkish hospitality, doing lunch at Topkapi Palace's former guard house. Then we'll immerse ourselves in the context and treasures of Topkapi, including the Treasury, Harem, and Holy Relics sections. Risking total sensory overload, we'll conclude our day at the Istanbul Archaeology Museum.



COMETS

Speaker: **Mark Bailey, Ph.D.**

Meteors, Meteor Showers, and the Draconids — Meteors or shooting stars are fragments of dust from comets, burning up in the Earth's atmosphere. The time of this lecture coincides with a predicted outburst of the annual Draconid meteor shower. It is expected that activity will increase to a peak over a 2- to 3-hour period beginning around 8pm, with up to several hundred meteors per hour possibly being seen, depending on local weather conditions. After a brief introduction to meteors and meteor storms, we go up on deck to observe the "dragon's" fiery flame.

Comets and Concepts in History — Humans have a love-hate relationship with comets. We'll look at the oldest theories of the nature of comets and the role they played in astronomy's development. Blaze a trail with Dr. Bailey through the historic observations, arguments, and theories leading to the realization that comets are largely Oort cloud products, formed with the Sun and planets 4.5 billion years ago.

The Life, Times, and Persistent Puzzles of Comets —Broaden your horizons delving into 20 years' worth of discoveries on comets and their origins — whether in the Edgeworth-Kuiper belt just beyond Neptune, the trans-Neptunian disc, or the Oort cloud. Survey the natural history of comets in the inner solar system, and discover the persistent puzzles and uncertainties in this vibrant, active field of solar-system research.

Risks Posed by Comets and Asteroids — Comets occasionally descend on the Earth with catastrophic effect. At one extreme, such impacts can change the course of evolution disrupting the normal "Darwinian" process. At another extreme, relatively small impacts may have important implications for the development of civilization. Find out how the risk of rare, high-consequence events is assessed.

EVOLUTION

Speaker: **Mohamed Noor, Ph.D.**

What is "Evolution" Anyway and Why Should I Care? — The mere word "evolution" conjures images in the public ranging from movie dinosaurs to something vaguely half-human-half-gorilla. What does the word evolution actually mean in the biological sciences, what is the evidence that it is true, and why should the general public know and care? In fact, evolution affects your everyday life, from your health to your livelihood — come learn why!

On the Origin of Species, Really — Although Darwin's book title suggested that he defined the origin of species, in fact, he only focused on the process of divergence within species and assumed the same processes "eventually" led to something that could be called a new species. Dr. Noor will talk about how species are identified (in practice and in principle), how to modern evolutionary biologists use this type of information to get a handle on how species are formed, and what questions remain.

Genetics, Genomics, and You: Don't Fear Your Genotype! — The missing element to Darwin's theory was how it worked in terms of inheritance. Genetics answered that. Today "personal genomics" issues span medical, legal, ethical, and other areas and pose big question. Get ready for discussion and a lab exercise to help understand the lingo, opportunities, and issues associated with living in the genomics era.

Life in the US Academic Sciences — What happens behind closed doors in the "Ivory Tower" of an academic scientist? Scientists at universities juggle multiple roles. What do these people actually do all day? What are these scientists trained well to do and what are areas where they really are not trained well? What is a typical career trajectory in the sciences, and how are scientists evaluated? Get an inside look from a noted academic.

ANCIENT ASTRONOMY

Speaker: **John Steele, Ph.D.**

Astronomy in Ancient Babylon —Cuneiform writing on thousands of clay tablets documents the astronomical activity of the ancient Babylonians. These texts circa the first millennium BC, include lists of astrological omens, astronomical observations, and calculations of the positions and phenomena of the moon and the planets. Join Dr. Steele to investigate the astronomical traditions of the ancient Babylonians and their invention of scientific astronomy.

Ancient Greek Astronomy — How could Ptolemy insist that the earth was the center of the Universe? The ancient Greeks didn't invent astronomy, but they were the first to combine philosophy with mathematics to model the motion of the heavens using geometry. Along the way they figured out the size of the Earth, the distance of the moon from the Earth, and developed geometrical methods for modeling planetary motion. Delve into the legacy of Greek astronomy, and trace its impact in the medieval Islamic world and Renaissance Europe.

The Antikythera Mechanism: An Ancient Mechanical Universe — In 1900 sponge divers off the tiny island of Antikythera discovered an ancient Roman shipwreck laden with works of art. Almost unnoticed were the poorly preserved remains of a small mechanical device — the Antikythera Mechanism. Through painstaking reconstruction and analysis over the past century, we now know the device was a mechanical astronomical computer of great ingenuity. Learn the story of research on the mechanism — and what it has revealed about ancient Greek science and technology.

Eclipses in History — Eclipses are one of the most awe-inspiring astronomical events. Throughout history eclipses were viewed with fear, excitement, astonishment, and scientific curiosity. Take a look at how eclipses have been observed, interpreted, and commemorated in different cultures around the world and discover how scientists today benefit from ancient eclipse records.

DRACONID METEOR SHOWER

"Every year around Oct. 8th, Earth passes through a minefield of dusty debris from Comet Giacobini-Zinner, source of the annual Draconid meteor shower. On Oct. 8, 2011, Earth will have a near head-on collision with a tendril of dust, setting off a strong outburst of as many as 750 meteors per hour. People in Europe, Africa and the Middle East will have a front-row seat for what could be the strongest shower since the Leonid storms a decade ago." From SpaceWeather.com.

ATHENS' BEST

Visit the new Acropolis Museum and the National Archaeological Museum with our skilled guide who will add immeasurably to your experience. See the Parthenon frieze, exquisite sanctuary relics, and Archaic sculpture at the Acropolis Museum. Lunch, of course, is tucked away at a taverna favored by Athenian families. For dessert, we'll visit the richest array of Greek antiquities anywhere at the National Archaeological Museum.

EPHESUS

Many civilizations left their mark at Ephesus. It's a many layered, many splendored history, often oversimplified. Bright Horizons pulls together three important elements of Ephesus rarely presented together. Meander the Marble Road, visit the legendary latrines, check out the Library, and visit the centers of the city. A visit to the Terrace Houses enlivens your picture of Roman Ephesus. Lunch on Mediterranean cuisine in the countryside, and then visit the Ephesus Museum where you get a fuller look at local history, from the Lydians to the Byzantines.

GEOLOGY

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

Changing Climates, the Black Sea Flood, and the Rise of Civilization — The philosopher Will Durant said, "Civilization exists by geologic consent, subject to change without notice." The history of climate change illustrates this richly. Dr. Wysession lays out the factors controling the climate and how climate change has been the driving factor for the course of human history. You'll get a detailed look at the Black Sea Flood of 7500 years ago, and enrich your understanding of the impact of climate change.

Santorini and the History of Megatsunamis — 3600 years ago, Thera/Santorini saw one of most powerful volcanic eruptions known, leaving just the island ring we see today, burying the Minoan city of Akrotiri under 60 feet of ash, creating a megatsunami that devastated the entire Mediterranean. The the U.S. Northwest's 1700 M-9 earthquake, Lisbon's 1755 quake, Krakatoa's 1883 eruption, and the devastating Sumatra 2004 quake created similarly catastrophic tsunamis. Survey the terrain of megatsunamis, and learn potential future tsunami triggers.

The Eruption of Vesuvius and the Impact of Volcanoes — The term "Plinian volcanic eruptions" honors Pliny the Elder who chronicled the 79 CE eruption of Vesuvius. These eruptions eject ash high in the atmosphere, having their greatest impact through global climate change. From Peru to Russia, from eruptions 74,000 BCE to the French Revolution, you'll focus on the impact of volcanos on history. Time well spent with Dr. Wysession, who keeps his eye on the Yellowstone Caldera!

Fermi's Paradox and the Likelihood of Finding Another Earth — During a discussion on the likelihood of intelligent civilizations existing elsewhere, the physicist Enrico Fermi asked "Well, where is everybody?" Geologic research shows that the conditions required for life to exist continuously for nearly four billion years are stringent, and may rarely occur in the galaxy. Learn all of the factors that had to happen just right to produce Earth's spectacular and potentially unique diversity of geologic and biologic environments.

SCIENTIFIC AMERICAN TRAVEL

BRIGHT HORIZONS

Fear and Its Consequences

With preventable diseases on the rise, the states should get strict on vaccines

Well-intentioned: Antivaccine advocates are misguided.

This winter in the San Francisco Bay Area, many children will sit in classrooms and play on the jungle gyms at recess and then go home to attentive parents who work hard to give them every advantage in life. Parents in this part of the country are better educated and wealthier than the average American and can give their children more opportunity. But the Bay Area is also a hotbed of the growing movement to abstain from vaccinations for fear that the shots cause autism and other disorders. Although these parents may have the best of intentions—to protect their kids—they are dangerously misguided.

California is now in the middle of the worst outbreak of pertussis in half a century. This highly contagious disease—known as whooping cough for the distinctive sound its victims make when gasping for air after a fit of paroxysmal coughing—was a scourge of childhood until the advent of an effective vaccine against it in the 1940s, which drastically reduced incidence of the disease. The number of annual cases has been climbing in recent years. Last year, though, the rate of infection rose, once again, to epidemic proportions—7,297 known and suspected cases, a fourfold increase from 2009. Whether those refusing the vaccine have helped fuel the current pertussis epidemic is uncertain, but their decisions have created a public health tinderbox: in some Bay Area schools, 40 percent or more of the kids are not vaccinated, leaving them unprotected against pertussis and other preventable diseases, such as measles.

California is hardly the only state grappling with antivaccine sentiment. Significant numbers of parents across the country are declining standard immunizations for their children. The success of any given vaccine depends on so-called herd immunity, in which a high rate of immunization in a population helps to protect those individuals who are not immune. Herd immunity requires high immunization rates—around 95 percent for highly contagious infections like pertussis and measles. When immunization rates drop below the critical level, disease can strike not only unvaccinated individuals but also vaccinated ones, because all vaccines fail to confer immunity in a certain percentage of people. Parents who opt out are endangering not only their own kids but everybody else's, too—including those who cannot be vaccinated because they are too young or immunocompromised, as well as youngsters who have received their shots.

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/feb2011

Vaccine anxiety has been around for as long as there have been vaccines, but the fear of autism originated with a paper published in the *Lancet* journal in 1998. On the basis of a study of 12 children, author and British medical doctor Andrew Wakefield claimed to have found a link between the measles-mumps-rubella (MMR) vaccine and an autismlike disorder. Antivaccination groups and the media pounced on the news, and before long the alleged vaccine-autism connection became a Hollywood cause célèbre; former actress and *Playboy* model Jenny McCarthy claims that MMR caused her son's autism.

In February 2010 the *Lancet* retracted Wakefield's infamous paper. That leaves no scientific evidence to support the assertion that vaccines cause autism or other chronic diseases. Unfortunately, fear is far easier to ignite than to extinguish. Some parents caught in the crossfire between scientists and charlatans have decided, against all reason, that the vaccines are more dangerous than the diseases they protect against.

They are wrong. Vaccines may provoke a low fever and other unpleasant symptoms. Very rarely, side effects are serious, such as an allergic reaction. The risk of unprotected exposure to vaccine-preventable diseases is far higher: for example, more than 90 percent of unvaccinated people exposed to measles will become infected.

Each state has its own immunization requirements for schoolchildren. Yet in 48 states parents may exempt their kids on the basis of religious or philosophical beliefs (only Mississippi and West Virginia disallow exemptions). The right to decide what is best for oneself and one's children ends where science has so clearly documented a threat to public welfare. It's time for the other 48 states to eliminate these exemptions and adopt strict enforcement policies to ensure that kids get their jabs. In the interim, doctors need to be patient but firm with fearful parents, explain why vaccines are essential and help restore the public's faith in science. SA

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THE PARTNERSHIP™
AT DRUGFREE.ORG

Commentary on science in the news from the experts

Francesca Grifo is senior scientist and director of the Scientific Integrity Program at the Union of Concerned Scientists in Washington, D.C.

The Bright Side of Gridlock

How to move the science agenda forward in the next two years

Many politicians swept into office in the last election in Congress and the state legislatures have shown little understanding of, or respect for, the enterprise of science. A number of the Republicans now in leadership positions in the House of Representatives, for instance, have expressed skepticism about climate change and are planning to use the subpoena powers of their office to put climate scientists on the defensive and portray efforts to curb carbon emissions as a job killer.

The prospect of two years of gridlock and troublemaking is worrying. But even as the nation descends into a period of anti-science populism, there may still be opportunities to begin shaping the science agenda for the next political cycle and perhaps get some useful things done in this one.

Some important measures, of course, are off the table for the near future: cap and trade, a carbon tax, and other comprehensive efforts to deal nationally with global warming. That, however, does not rule out smaller market-based bipartisan efforts that could reduce our energy use and take steps toward a clean energy economy. The next Congress might well consider policies that encourage energy efficiency, incentives for the production of renewable technologies, and other tax-credit measures because these create jobs in many of their home districts.

COMMENT ON THIS ARTICLE ONLINE
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Meanwhile states and local governments are already marching forward. On November 3 California voters defeated Proposition 23, which would have effectively suspended California's effort to cut emissions to 1990 levels within 10 years. Proposition 23 was defeated in part by showing that reduced emissions could increase employment. As the world's eighth-largest economy, California will propagate proven emission-cutting products and policies that will seem commonplace when the nation is ready to take up the issue again.

California isn't alone. More than 1,000 mayors have signed on to the U.S. Mayors Climate Protection Agreement. Twenty-nine states and the District of Columbia have enacted renewable electricity standards. The Western Climate Initiative, which includes seven states and four Canadian provinces, has negotiated a regional cap-and-trade program. Scientists are designing energy generation technology for remote regions and communities.

Even dark clouds can have silver linings. Some congressional leaders have already started beating the drums for sweeping investigations of the Obama administration and mainstream science. Climate scientists, in particular, may be summoned before House committees to defend their work. Such hearings could backfire, however, by giving scientists a forum for making their voices heard. A calm, well-reasoned argument, based on firm evidence, could do much to persuade people that climate science is solid and all but universally accepted by legitimate researchers.

Republicans and Democrats may still be able to work together. Incoming freshman representatives may be more sympathetic to scientific issues once they face the task of governing. The need for a record of accomplishments for the 2012 elections may open other doors for legislative change. And the Republican Pledge to America, which advocates transparency in government, leaves open the possibility for progress on protecting whistleblowers who report abuses of science in federal decision making.

President Barack Obama still wields executive power. He can require emissions cuts from motor vehicles, push for developing solar plants on public lands, protect the Environmental Protection Agency's authority to regulate greenhouse gases and move quickly to implement his directive on restoring scientific integrity to federal policy making.

Progress won't be easy. It will require the persistent and energetic engagement of the scientific community. Many scientists and scientific societies are focused too narrowly on shrinking budgets and spend precious little energy on other science-related issues, even in the face of withering, well-funded attacks. This silence, and the ubiquity of the attacks, has left the public confused. Scientists and citizens must respond with courage and clarity. SA

Illustration by John Cuneo

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Actual coin size is 38.1 mm. Note: GovMint.com is a private distributor of worldwide government coin issues and is not affiliated with the United States government. Facts and figures were deemed accurate as of April 2010. ©GovMint.com, 2011

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

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

Early software translators 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 and emerging standards, computers can now understand and translate software applications with levels of proficiency that vastly exceed human performance. This technology is revolutionizing the way industries, such as finance, insurance, manufacturing, and healthcare as well as military and governments are modernizing their legacy systems.

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

• **European Air Traffic Management System (EATMS), Thales Air Systems:** This realtime system manages over 10 million passenger flights annually. Thales engaged TSRI to transform EUROCAT's 2 million lines of legacy Ada into Java. The result was a perfect functional replica of EUROCAT in its new language. TSRI's 100% automation eliminated the risk of errors inherent in a manual rewrite. EUROCAT will commence operation in significant airports across Europe and Asia at the end of 2011.

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

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

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

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

Information Systems Transformation: *Architecture-Driven Modernization Case Studies* provides more detailed information on these case studies.

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

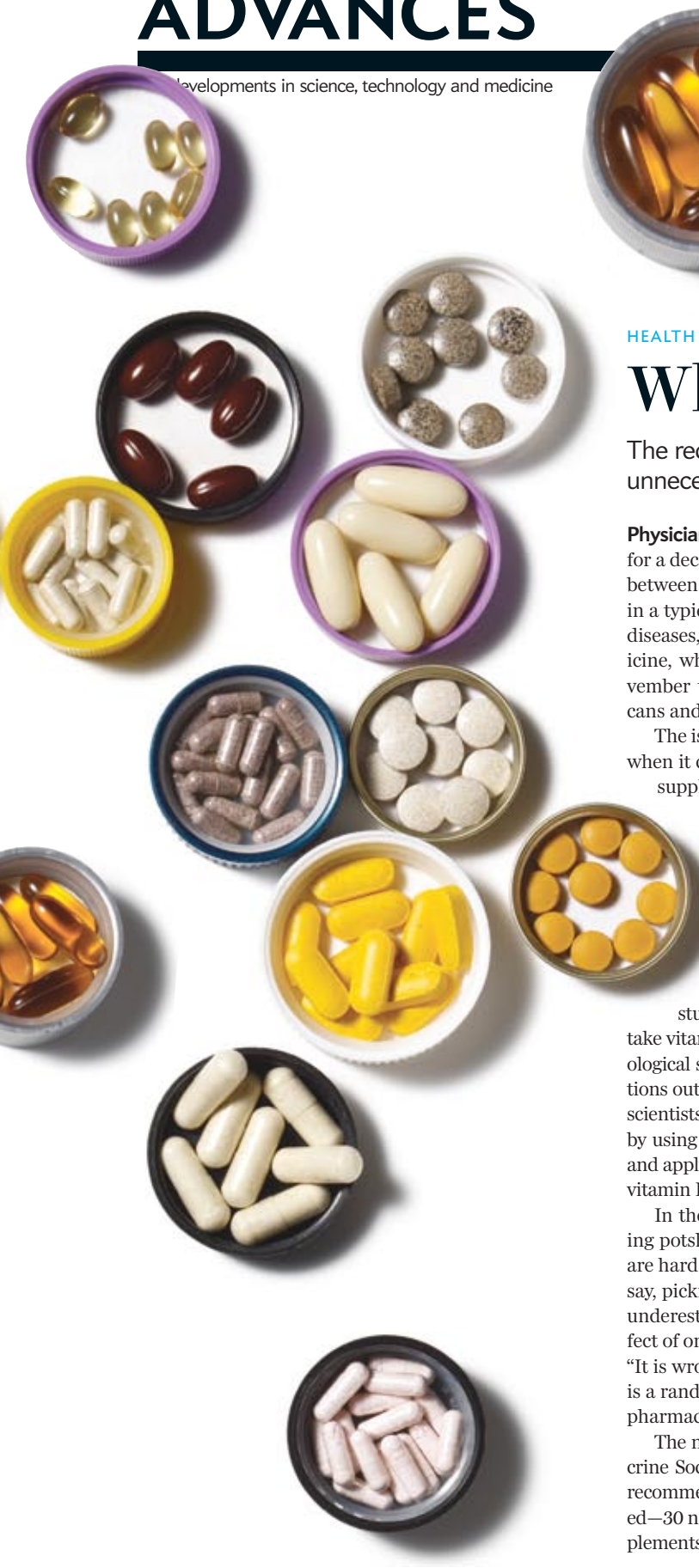
Information Systems Transformation:
Architecture-Driven Modernization Case Studies
By William M. Ulrich and Philip Newcomb
ISBN: 978-0123749130

About the book:
Architecture-Driven Modernization (ADM) gives you everything you need to know 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 expert 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® tool suite. 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® tool suite have served as the leading exemplar for the OMG's emerging ADMTF standards.



HEALTH

Which Pills Work?

The recent finding that vitamin D supplements are largely unnecessary exposes a rift among nutrition researchers

Physicians have recommended vitamin D supplements to their patients for a decade, with good reason: dozens of studies have shown a correlation between high intake of vitamin D—far higher than most people would get in a typical diet and from exposure to the sun—and lower rates of chronic diseases, such as cancer and type 1 diabetes. So when the Institute of Medicine, which advises the government on health policy, concluded in November that vitamin D supplements were unnecessary for most Americans and potentially harmful, patients were understandably confused.

The issue exposes a rift among experts over what constitutes valid proof when it comes to nutrition and could affect medical advice on many other supplements. On the one hand are scientists who insist that the only acceptable standard is the randomized clinical trial, which often compares the effects of a medical intervention, such as high intake of vitamin D, with those of a placebo. The scientists who reviewed the vitamin D findings fall heavily into this camp: trials "typically provide the highest level of scientific evidence relevant for dietary reference intake development," they wrote. Their report set intake levels based only on clinical trial data.

The institute panel, however, discarded a raft of observational studies, in which researchers compare the health of populations who take vitamin D supplements with those who do not. In theory, such epidemiological studies are inferior to clinical studies because they rely on observations out in the real world, where it is impossible to control for the variables scientists seek to understand. Researchers compensate for the lack of control by using large sample sizes—some vitamin D studies track 50,000 people—and applying statistical techniques. According to these studies, high levels of vitamin D are generally beneficial.

In the aftermath of the institute report, some physicians are now taking potshots at clinical studies. In nutrition, they say, true placebo groups are hard to maintain—how do you prevent people in a control group from, say, picking up extra vitamin D from sunlight and food, which can lead to underestimating the vitamin's benefits? It is also tough to single out the effect of one vitamin or mineral from others, because many work in tandem. "It is wrong-headed thinking that the only kind of evidence that is reliable is a randomized controlled trial," says Jeffrey Blumberg, a Tufts University pharmacologist.

The next chapter in this debate may come in the spring, when the Endocrine Society releases its own vitamin D guidelines. The organization now recommends higher blood levels of the vitamin than the institute suggested—30 nanograms per milliliter as opposed to 20—which would require supplements. Stay tuned.

—Melinda Wenner Moyer

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COMMENT AT ScientificAmerican.com/feb2011

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Photo by Randall Slavin

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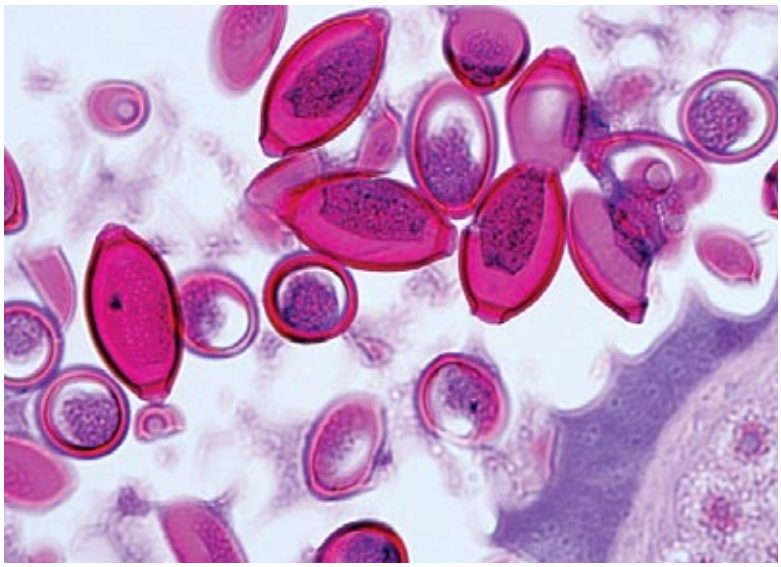


KIMBERLEY EVASON *University of California, San Francisco (micrograph);* LORI ADAMSKI PEEK *Getty Images (cat)*

IMMUNOLOGY

They Like Your Guts

Intestinal parasites may offer protection from colitis, asthma and other common ailments

In 2007 parasite immunologist P'ng Loke sat down for lunch at a University of California, San Francisco, cafeteria with a patient who wanted help documenting his medical condition. The two shared an unusual interest: gut worms—specifically, tiny wormlike parasitic organisms called helminths.

Loke's 35-year-old guest, who declined to be identified for reasons of patient confidentiality, explained that he suffered from an inflammatory bowel disease known as ulcerative colitis. While researching his condition a few years before, the man had read about helminthic therapy, which has not been approved by the FDA but which is a subject of active research by gastroenterologists and parasitologists. The idea is that people with autoimmune disorders can ease their symptoms by deliberately infecting themselves with parasitic worms such as hookworm or whipworm, both of which supposedly pacify the human immune system to survive inside the body. In numerous animal studies, these parasites ostensibly protected rodents from a wide variety of immunological disorders, including colitis, asthma, rheumatoid arthritis, food allergies and type 1 diabetes. The man had convinced himself the therapy could work for him, and, since 2004, he had been ingesting whipworm eggs, which he obtained from Thailand. He was now virtually symptom-free. Could Loke help him figure out how, if at all, the worms had treated his colitis?

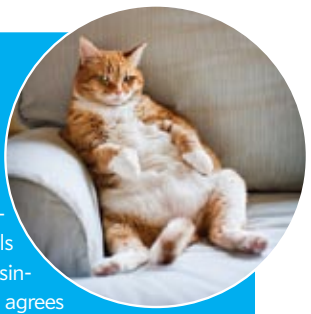
Loke was skeptical at first but agreed. In a recent paper published in *Science Translational Medicine,* Loke, now at New York University, and his colleagues suggest that the whipworms are indeed effective in treating colitis. Repeated colonoscopies, for example, showed that wherever worms colonized the patient's colon, the signs of colitis—open sores and inflammation—were significantly reduced or nonexistent. More important, Loke showed through tissue analysis that the parasites may work by stimulating mucus production in the gut. Colitis, which is associated with decreased mucus production, is thought to occur when the immune system attacks benign bacteria living in the intestines. The extra mucus may help calm the immune system and prevent it from attacking the gut's harmless microorganisms.

"This is not a double-blind study, but the pattern is highly suggestive that the worms helped this patient," says Joel Weinstock, a gastroenterologist at Tufts University who has pioneered helminthic therapy research. "The major point of this paper is the potential mechanism—mucus production—which has not been looked at properly before." *—Ferris Jabr*

BIOSTATISTICS

Does This Collar Make Me Look Fat?

The obesity epidemic is affecting animals, too



Weight gain is usually blamed on poor diet and a lack of exercise. But the marmosets and macaques living at a Madison, Wis., laboratory have followed the same diet and exercise regimens since 1982. Still, they grew heavier with each passing decade, leading David B. Allison, a biostatistician at the University of Alabama at Birmingham, to believe that environmental factors may be at play. He and his colleagues studied weight changes in 20,000 animals, including primates and rodents used for research, domestic cats and dogs, and urban feral rats. They tracked the animals' percentage weight gain per decade, as well as their odds of being obese. Both showed a strong upward tendency. Chimpanzees grew 33.6 percent heavier per decade; mice grew 12.46 percent heavier.

Allison speculates that factors such as endocrine-disrupting toxins in the water supply or pathogens affecting mammalian metabolism may be to blame. But some say his data could be explained by diet and exercise changes—caused, perhaps, by an increase in the numbers of lab animals being housed in a single cage. Allison agrees that housing might affect metabolism, but humans, too, live in increasingly crowded conditions. "This is exactly the kind of innovative thinking … we think our results warrant," he says. "If density of housing affects weights in animals, maybe density of housing also affects body weight in humans."

—Alla Katsnelson, Nature

COMMENT AT ScientificAmerican.com/feb2011

FIELD NOTES

The Bird Man of Baghdad

An unassuming 32-year-old ornithologist, in the midst of war and chaos, continues to add to the store of knowledge about Iraq's assorted bird life

I grew up in the city of Baghdad, but on weekends the men in my family—my brother, grandfather, father and I—would go off into the country to practice falconry. Passed down through the generations, this sport is something I still love.

As a child, I became fascinated by birds of prey, like falcons and other raptors, but also by the birds that serve as prey, like the houbara (*above*), a timid, turkeylike species. Birds became my life, and I continue to pursue that passion through my work at the University of Baghdad, where I do research on the ecology of endangered falcons and other birds of prey. My job takes me to every part of the country, even areas that are still very dangerous and that have been torn apart by war.

PROFILE

NAME
Omar Fadhil

TITLE
M.A. student in biology and laboratory teacher, University of Baghdad

LOCATION
Baghdad, Iraq

In the spring of 2009 I got a call from a group that I collaborate with that had used radio/GPS tags to track a critically endangered migratory bird called the sociable lapwing to an area near Tikrit, the ancestral home of Saddam Hussein. The birds migrate every spring from Sudan to their summer home in Kazakhstan.

Bird-watching in Iraq is not like bird-watching in a U.S. national park. To make these trips, I need official endorsements from the police and various ministries. After receiving the requisite permissions, we set out with a convoy of 15 soldiers and made our way to the point near the Euphrates River where the lapwing had set down. We scoured the countryside for 13 days, but the birds, always highly mobile during the course of a migration, had already moved on. The area was a resting spot not just for lapwings but also for Al-Qaeda in Iraq, and months later two long-sought leaders were killed near where we had searched.

Whenever I go out, villagers always ask, "What the hell are you doing here?" I never engage them directly. Instead I get out my binoculars, set up the camera tripod and take out my bird books. I show them pictures of the birds I'm looking for and, when possible, let them look through the binoculars at the birds themselves.

After a time, they often warm to me. They point to a bird in the book and say, "We've seen this one but not that one." They become my scouts. Despite the war, I have found six new species that had never been seen before in Iraq. *—As told to Gary Stix*

QUOTABLE

"Fifty years later our generation's Sputnik moment is back."

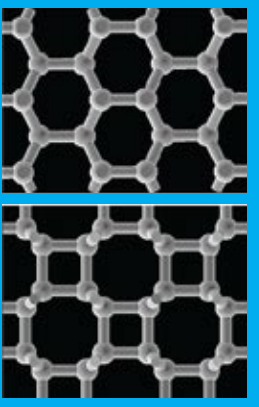
President Barack Obama on international test results showing that 15-year-olds in Shanghai bested Americans in reading, science and math by a wide margin.

OMAR FADHIL, *Nature Iraq*

COMMENT AT ScientificAmerican.com/feb2011

MATERIALS SCIENCE

Not Your Parents' Carbon



Pure carbon can take a great variety of forms. Diamond, carbon nanotubes and graphene—the last the subject of the 2010 Nobel Prize in Physics—all have unique physical and chemical qualities and applications to technology. Now evidence is mounting that there is yet another crystal structure to add to carbon's catalogue of wonders: a material that could find applications in mechanical components whose hardness varies depending on the pressure to which they are exposed.

This new type of carbon was first observed in 2003, when researchers placed graphite, a stacking of chicken-wire-shaped networks of carbon atoms, under high pressure at room temperature. Under this "cold" compression, the graphite began to assume a hybrid form, between that of graphene and of diamond, but its exact nature was unknown.

Two computer simulation studies now suggest that cold-compressed graphite contains crystals of a structure called body-centered tetragonal, or bct, in addition to another type called M carbon. In bct, groups of four atoms are arranged in a square. The squares are stacked in an offset manner, and each square forms chemical bonds with four squares in the layers above and four below. A team led by Hui-Tian Wang of Nankai University in Tianjin, China, showed that during cold compression the transition to bct carbon results in a release of energy, which means it is likely to happen in the real world.

A Japanese and American team also conducted a simulation in which bct carbon produced x-ray patterns similar to those seen in the 2003 study. The match between the simulation and the experiment is quite good, says Wendy L. Mao of Stanford University, who was part of the 2003 discovery. Whether bct carbon exists or can be synthesized in its pure form "is still a task for experimentalists to test." —*Davide Castelvecchi*

FROM "AB INITIO STUDY OF THE FORMATION OF TRANSPARENT CARBON UNDER PRESSURE," BY XIANG-FENG ZHOU ET AL., IN *PHYSICAL REVIEW B*, VOL. 82, NO. 13; OCTOBER 29, 2010 (*bct*); RUSTY HILL *Getty Images: (beer)*

FOOD

Beer Batter Is Better

How it makes a great fish 'n' chips

If you've ever sat down at a pub to a plate of really good fish and chips—the kind in which the fish stays tender and juicy but the crust is supercrisp—odds are that the cook used beer as the main liquid when making the batter. Beer makes such a great base for batter because it simultaneously adds three ingredients—carbon dioxide, foaming agents and alcohol—each of which brings to bear different aspects of physics and chemistry to make the crust light and crisp.

Beer is saturated with CO_2. Unlike most solids, like salt and sugar, which dissolve better in hot liquids than they do in cold, gases dissolve more readily at low temperatures. Put beer into a batter mix, and when the batter hits the hot oil, the solubility of the CO_2 plummets, and bubbles froth up, expanding the batter mix and lending it a lacy, crisp texture.

That wouldn't work, of course, if the bubbles burst as soon as they appeared, as happens in a glass of champagne. Instead beer forms a head when poured because it contains foaming agents. Some of these agents are proteins that occur naturally in the beer, and some are ingredients that brewers add to produce a creamy, long-lasting head. These compounds form thin films that surround the bubbles and slow the rate at which they burst.

Foams also make good thermal insulators. When you dunk a piece of beer-battered fish into a deep fryer, most of the heat goes into the batter rather than into the delicate food it encloses. The bubbly batter can heat up to well over 130 degrees Fahrenheit—the point at which so-called Maillard reactions create golden-brown colors and yummy fried flavors—while the fish gently simmers inside.

The alcohol in the beer also plays an important role in moderating the internal temperature and crisping the crust. Alcohol evaporates faster than water, so a beer batter doesn't have to cook as long as one made only with water or milk. The faster the batter dries, the lower the risk of overcooking the food. If the chef works fast enough, he can create a beautiful lacework in the coating that yields that classic beer-batter crunch.

—*W. Wayt Gibbs and Nathan Myhrvold*

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

NEUROSCIENCE

You Smell Flowers, I Smell Stale Urine

Each of us lives in our own olfactory world

Scientists have long known that people perceive scents differently. But emerging evidence from several large-scale studies shows that the variation is larger than previously known. It turns out that people differ in how they perceive many if not all odors, and most of us have at least one scent we cannot detect at all. "Everybody's olfactory world is a unique, private world," says Andreas Keller, a geneticist at the Rockefeller University.

Over the course of evolution, partly because humans grew more reliant on vision and smell became relatively less important, the genes encoding our 400 or so olfactory receptors began to accumulate mutations. Once a gene has accumulated enough mutations, it becomes a "pseudogene," notes geneticist Doron Lancet of Israel's Weizmann Institute of Science, meaning it no longer encodes a functioning receptor. Different people have different combinations of pseudogenes, however. "You end up with a bar code situation, whereby each individual has a slightly different bar code," he says.

That genetic variability seems to translate into behavioral variability. When Keller and his colleagues asked 500 people to rate a panel of 66 odors for intensity and pleasantness, they gave the full range of responses—from weak to intense and from pleasant to unpleasant. In an ongoing study at the University of Dresden, Thomas Hummel and his associates have tested 1,500 young adults on a panel of 20 odors and found specific insensitivities to all but one—citralva, which has a citrus smell. Based on these findings, Keller suspects that each person has an olfactory blind spot.

These studies have wider implications than smell, Lancet says. Because several genes contribute to the detection of most odors, understanding the genetics of olfaction and the way mutations spread in a population is yielding insights into the mechanisms of polygenic diseases such as coronary heart disease and diabetes.

—Laura Spinney

WHAT IS IT?

Death by plastic: *Much of the 260 million tons of plastic the world uses every year winds up in the oceans, threatening marine life. Indeed, a mass of floating trash, called the Great Pacific Garbage Patch, has been observed in the northern part of the ocean. Over the past two years photographer Chris Jordan has documented the affect the plastic debris has had on wildlife on Midway Atoll, which is northwest of the Hawaiian Islands. This three-square-mile area is home to the albatross, the world's largest flying bird. Albatross parents often mistake colorful debris for sea life and feed it to their chicks, which can prove fatal. "There's a dead bird every 10 steps in different decomposed stages," Jordan says. He photographed the chicks and the contents of their stomachs: bottle caps, lids from tops of spice bottles, lighters and other fragments.* —Ann Chin

STEVE LEWIS Getty Images (noses); CHRIS JORDAN (bird)

COMMENT AT ScientificAmerican.com/feb2011

PHYSICS

Forces to Reckon With

Does gravity muck up electromagnetism?

A magazine news story on the unification of physics usually begins by saying that Einstein's general theory of relativity and quantum theory are irreconcilable. The one handles the force of gravity, the other takes care of electromagnetic and nuclear forces, but neither covers all, so physicists are left with a big jagged crack running down the middle of their theoretical world. It's a nice story line, except it's not true. "Everyone says quantum mechanics and gravity don't get along—they're incompatible," says John F. Donoghue of the University of Massachusetts at Amherst. "And you still hear that, but it's wrong."

The famous physicist Richard Feynman came up with a seamless quantum theory of gravity in the 1960s. It looks much like the quantum theories of the other forces. Just as photons convey the force of electromagnetism, particles called gravitons convey the force of gravity. Where the forces differ is that electromagnetism behaves in essentially the same simple way on all scales, varying only in its general strength, whereas gravity becomes increasingly rococo as you zoom into microscopic scales—signaling that the theory eventually gives way to a deeper one such as string theory or loop quantum gravity. But "eventually" is so far off that physicists can usually neglect the rocococity. In the 1990s Donoghue and others began to use Feynman's theory as a working, or "effective," theory; though not the final word, it closes up the crack between gravity and the other forces on medium to large scales.

In 2006 Sean P. Robinson and Frank Wilczek of the Massachusetts Institute of Technology applied the effective theory to see whether gravity changes the way forces vary in strength with scale. If gravity doesn't interfere, electromagnetism should become equal in strength to the nuclear forces at one scale and to gravity at a different scale. Robinson and Wilczek conjectured that gravity saps the strength of the other forces and causes them all to match up at the same scale. The idea didn't pan out but did get people thinking about how the forces mess with one another.

Last November, David J. Toms of Newcastle University in England argued that even if gravity does not bring all the forces into line, it at least qualitatively reconciles electromagnetism with the nuclear forces. Neglecting gravity, electromagnetism intensifies as you go down in size, whereas the nuclear forces weaken. But gravity emasculates electromagnetism, causing it to behave like the nuclear forces on the very smallest scales.

Wilczek calls Toms's paper "impressive." Around the same time, however, Donoghue and his graduate students Mohamed M. Anber and Mohamed El-Houssieny cast doubt on the whole approach. Although gravity surely interferes with the other forces in some way or other, they question whether the effect is so straightforward as a tweak to the force strength. The rocococity of gravity should infect the other forces.

One reason physicists can reach such diametrically opposite conclusions is that the calculations are complicated and no one yet knows how to interpret them. "I really wish I had a physical understanding of what is going on, and I don't," Toms says. To paraphrase Ernest Rutherford, discoverer of the atomic nucleus, physicists don't consider they have understood something unless they can explain it in plain language to a bartender. Fortunately for quantum gravity theorists, the bartenders of the world are a patient group. —*George Musser*

QUOTABLE

"Someone else's cow may moo, but yours had better keep quiet."

Russian Prime Minister Vladimir Putin on how the U.S., a self-styled defender of Internet freedom, reacted hypocritically to the WikiLeaks scandal. Putin was quoting a Russian proverb that translates roughly to "look who's talking."

INFECTIOUS DISEASE

Charging against the Flu

A giant magnet is illuminating how the influenza A virus mutates to resist drugs

With the flu now resistant to its two most common medications, doctors and drug developers have grown increasingly puzzled about how to treat the virus. A 900-megahertz magnet is offering some new clues. Biochemists at Florida State University and Brigham Young University have used a 40-ton magnet to obtain atomic-level images of the virus, not only confirming how the bug escapes annihilation but also revealing potential pathways for new drugs.

The study focused on influenza A, the virus responsible for pandemic strains—more specifically, on one of the virus's surface proteins known as M2, which plays an important role in reproduction. Antiviral drugs amantadine and rimantadine, which for years were the most widely used against influenza A viruses, plugged the M2 pathway like bathtub stoppers, preventing reproduction. Over the years, however, changes in M2's shape enabled it to slip by those stoppers and avoid eradication; in 2006 the Centers for Disease Control and Prevention recommended against the use of these two drugs. Although the general mechanism of resistance has been known for some time, exactly how M2 functions was less clear.

The big magnet gives an inside view of the virus, much like magnetic resonance imaging can be used to peer inside our limbs and organs. The approach, called solid-state nuclear magnetic resonance spectroscopy, delivers images similar to MRI, but with key differences. The magnetic field generated during an MRI scan spins the hydrogen in water molecules into alignment. The resulting image—of a knee, a brain, a tumor—is a snapshot of the molecules as they return to their normal charge; different tissues "spin down" at different speeds. But the M2 protein exists at the water-repellent cell membrane, making MRI scans impossible. The charged field generated by NMR spectroscopy can spin elements other than hydrogen, making it possible to image proteins that do not live in a watery medium. In addition, samples can be frozen, making observations of slippery proteins like M2 easier.

By focusing on nitrogen atoms, Timothy A. Cross of Florida State University and his co-workers were able to determine exactly how M2 functions. They found that the protein, shaped like a channel with pores at both ends, has to be activated by an acidic environment to function. Two amino acids—histidine and tryptophan—set the process in motion: histidine carries protons from the host cell into the viral interior, and tryptophan acts as a gate, swinging open when the protons arrive. This passage of protons through the M2 pores is what allows the virus to reproduce.

According to the findings, reported recently in *Science,* M2's mechanism is completely unique, which could be good news for drug developers. "Maybe we can design a drug that would specifically target this [novel] chemistry," says Cross, who notes that the virus's reliance on M2 might make mutating against such a specialized drug difficult.

Cross and his team are screening drug compounds against the virus but have yet to identify serious candidates.

—Jessica Wapner

BIOLOGY

Blame It on Winter

Exposure to daylight may explain a link between birth season and mental illness

Several recent studies have suggested that winter-born babies are more likely than summer ones to develop conditions such as schizophrenia, depression and seasonal affective disorder (SAD). One study may help explain why: the amount of daylight to which newborn mice are exposed sets the behavior of key biological clock genes for life.

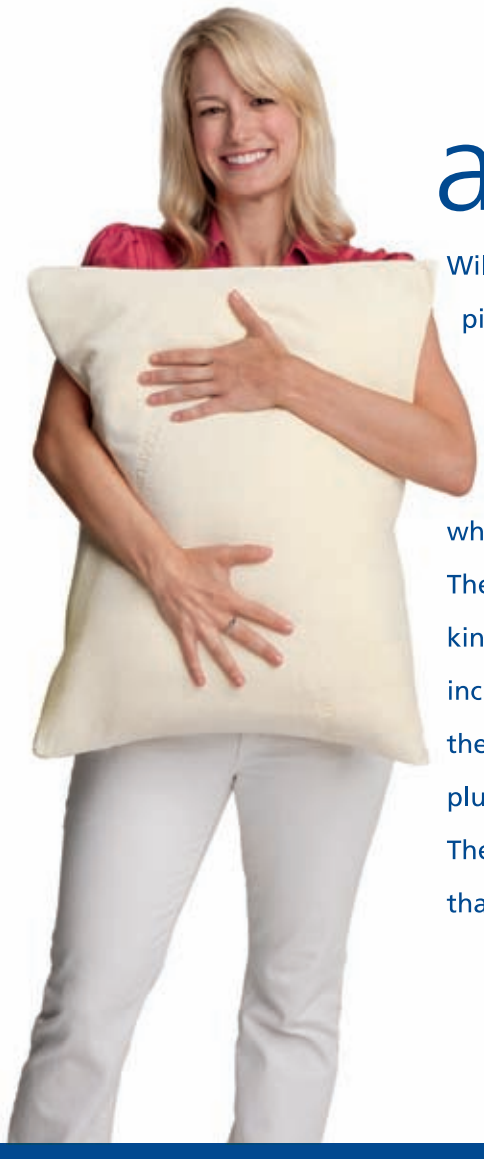
A group of researchers from Vanderbilt University and the University of Alabama at Birmingham raised one group of mouse pups as if it were winter, giving them eight hours of sunlight a day, and a second group as if it were summer, with 16 hours of sunlight a day. Then they exposed them to either the same light schedule or the opposite for an additional four weeks. Compared with the "summer" pups, the "winter" pups' biological clock genes were turned on for shorter periods regardless of the day lengths they were exposed to postweaning. The winter pups were also more active at night, similar to patients with SAD, suggesting their clocks were not as well aligned to the time of day. But don't buy a UV light for the nursery just yet. Researchers are still working to determine what effect these seasonal signals have on humans. *—Melinda Wenner Moyer*

CORDELIA MOLLOY Photo Researchers, Inc. (magnet); AARON McCOY Getty Images (baby)

COMMENT AT ScientificAmerican.com/feb2011









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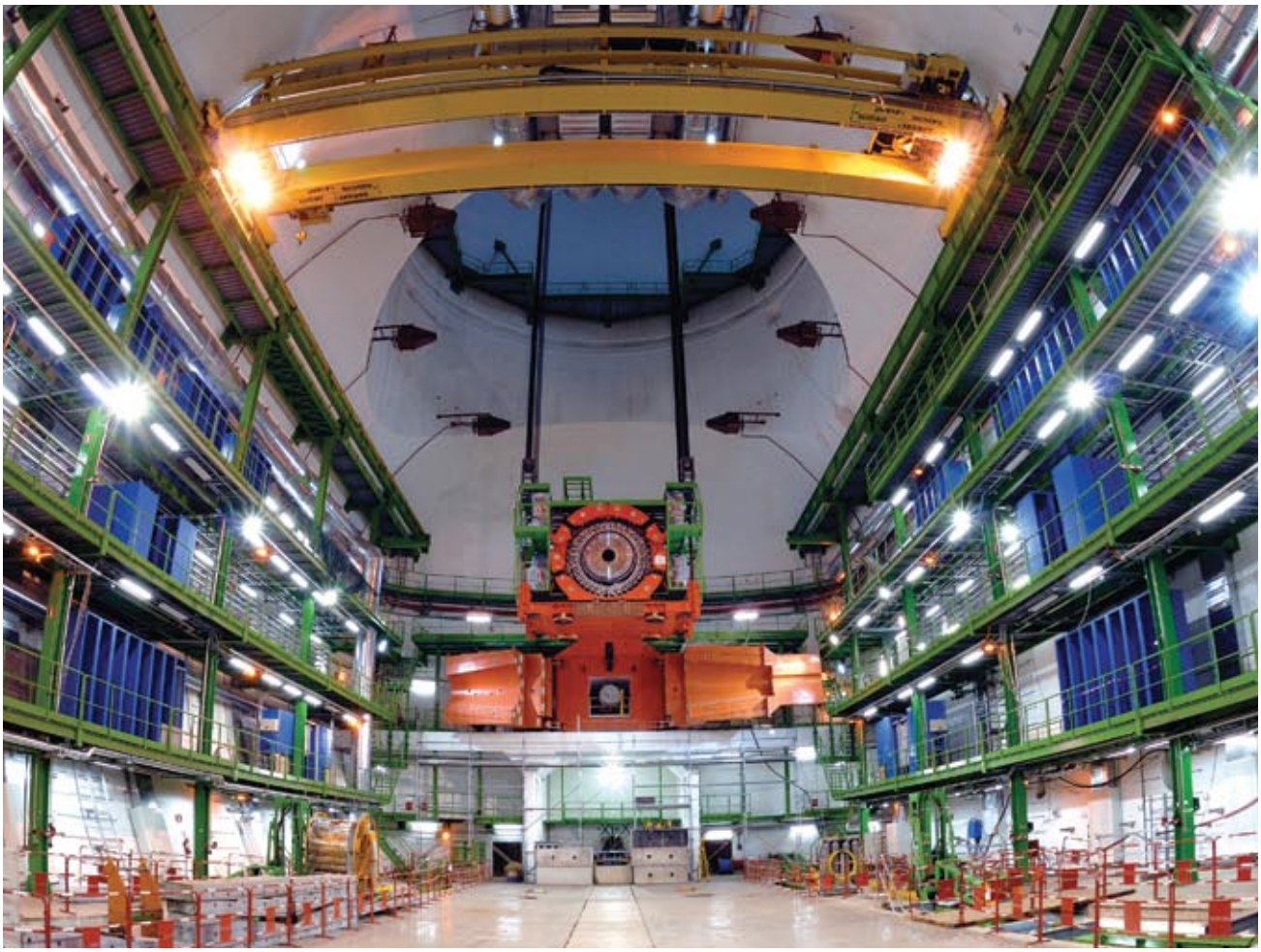

PHYSICS

Particles That Flock

Scientists at the Large Hadron Collider are trying to solve a puzzle of their own making: why particles sometimes fly in sync

In its first six months of operation, the Large Hadron Collider near Geneva has yet to find the Higgs boson, solve the mystery of dark matter or discover hidden dimensions of spacetime. It has, however, uncovered a tantalizing puzzle, one that scientists will take up again when the collider restarts in February following a holiday break. Last summer physicists noticed that some of the particles created by their proton collisions appeared to be synchronizing their flight paths, like flocks of birds. The findings were so bizarre that "we've spent all the time since [then] convincing ourselves that what we were see ing was real," says Guido Tonelli, a spokesperson for CMS, one of two general-purpose experiments at the LHC.

The effect is subtle. When proton collisions result in the release of more than 110 new particles, the scientists found, the emerging particles seem to fly in the same direction. The high-energy collisions of protons in the LHC may be uncovering "a new deep internal structure of the initial protons," says Frank Wilczek of the Massachusetts Institute of Technology, winner of a Nobel Prize for his explanation of the action of gluons. Or the particles may have more interconnections than scientists had realized. "At these higher energies [of the LHC], one is taking a snapshot of the proton with higher spatial and time resolution than ever before," Wilczek says.

When seen with such high resolution, protons, according to a theory developed by Wilczek and his colleagues, consist of a dense medium of gluons—massless particles that act inside the protons and neutrons, controlling the behavior of quarks, the constituents of all protons and neutrons. "It is not implausible," Wilczek says, "that the gluons in that medium interact and are correlated with one another, and these interactions are passed on to the new particles."

If confirmed by other LHC physicists, the phenomenon would be a fascinating new finding about one of the most common particles in our universe and one scientists thought they understood well.

—Amir D. Aczel

Aczel is author of Present at the Creation: The Story of CERN and the Large Hadron Collider.

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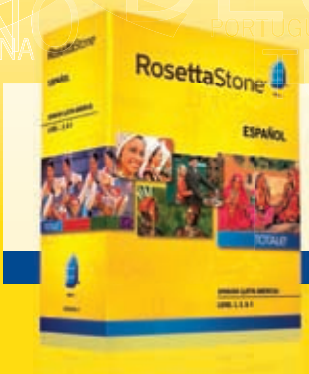

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GEOLOGY

When Earth Was a Snowball

New evidence links melting glaciers with the evolution of life

It took a mere 85 million years—the geologic blink of an eye—for animals to evolve and radiate out over much of the world's land and oceans. Although fossil records and molecular biology have provided much information on the spread of animal life, scientists have not been able to figure out exactly what sparked this massive diversification. New research shows that nutrient-rich runoff from massive melting glaciers may have provided the extra energy needed to fuel this dramatic evolution.

In the 1990s several scientists found evidence that much of Earth's surface was covered with glaciers 635 million to 750 million years ago. They called their hypothesis "Snowball Earth." Since then, many other studies have confirmed that it once may have been possible to ski from pole to pole. As the glaciers advanced, they scraped off the top layer of rock and soil on land and then released minerals and nutrients into the ocean as they retreated.

The moment of glacial runoff coincided with the rapid evolution of animal life. Biogeochemists Timothy W. Lyons and Noah J. Planavsky of the University of California, Riverside, knew as much, but what they could not understand was whether the runoff contained enough nutrients to spur animal evolution and whether the appearance of animals in the fossil record at this time was merely a coincidence. If they could measure phosphorus, a key nutrient in biological systems known to support the growth of microbes and algae, Lyons and Planavsky could surmise the total nutrient concentration. The problem was finding a way to measure the phosphate concentrations of oceans nearly one billion years old.

Lyons and his colleagues realized they could use iron-rich deposits from ancient, low-oxygen oceans high in dissolved iron to estimate how much phosphorus was in the water. "These iron-rich deposits scavenge phosphates in a very predictable and well-understood way," says Lyons, who published his and Planavsky's research recently in *Nature*. (*Scientific American* is part of Nature Publishing Group.) This discovery enabled the researchers to calculate marine phosphate concentration based on the phosphates in the iron-rich deposits. As the team expected, phosphate levels spiked in seven different samples around the world as the glaciers melted.

"A big pulse of phosphate would have supported a lot of life in the ocean," Lyons says. This phosphate buffet would have encouraged the abundance of oxygen-producing algae and other organisms and increased oxygen levels spurring the explosion of animal evolution.

"This study links Earth's geochemical systems with the evolution of life," says Gabriel Filippelli of Indiana and Purdue Universities, who was not involved with the study. It also shows how one big chill might have changed life on Earth forever. —*Carrie Arnold*

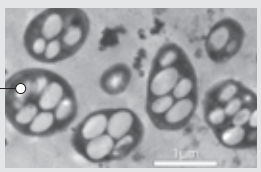
Mother glacier: The Larsen ice shelf on the east coast of the Antarctic peninsula.

NEWS SCAN

Genius

Astrophysicists estimate the universe contains 300,000,000,000,000,000,000,000 stars—three times as many as previously thought. Planets, of course, are extra.

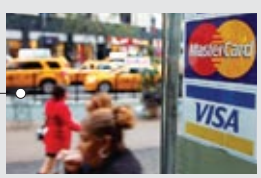
A study of the benefits of low-dose aspirin against heart disease reveals that the drug also cut the risk of death from many cancers.



1. NASA hints at discovery of extraterrestrial life-form. 2. Actually it's an Earth-based microbe … but it eats arsenic! 3. Other scientists call the research shoddy.

Western countries shocked that teenagers in Shanghai trounce them in math, science and reading scores. Not shocking: they studied harder.

Calcium and vitamin D supplements are probably unnecessary for most people, adding to the list of contradictory advice.



Self-styled WikiLeaks "avengers" cause shutdowns of "enemy" Web sites, including Visa, MasterCard … and Sarah Palin.

Folly

—*George Hackett*

COURTESY OF NOEL GOURMELEN (*ice shelf*); GETTY IMAGES (*star paths*); COURTESY OF SCIENCE/AAAS (*micrograph*); FRITZ HOFFMANN/*Corbis* (*students*); MARK LENNIHAN/*AP Photo* (*credit-card sign*)

COMMENT AT ScientificAmerican.com/feb2011

DO THE MATH

Why You're Probably Less Popular Than Your Friends

Where averages and individual perspectives diverge

DAVID MALAN Getty Images

Are your friends more popular than you are? There doesn't seem to be any obvious reason to suppose this is true, but it probably is. We are all more likely to become friends with someone who has a lot of friends than we are to befriend someone with few friends. It's not that we avoid those with few friends; rather it's more probable that we will be among a popular person's friends simply because he or she has a larger number of them.

This simple realization is relevant not only to real-life friends but also to social media. In Twitter, for example, it gives rise to what might be called the follower paradox: most people have fewer followers than their followers do. Before you resolve to become more scintillating, remember that most people are in similar, sparsely populated boats.

The number of friends we have is typical of many situations in which the average deviates from individuals' experience. Another is class size. Let's imagine a small department offering three courses for the semester. One is a survey course with 80 students, one an upper-level course with 15 students, and one a seminar with five students. Now what is the average class size? Clearly, it is $(80 + 15 + 5)/3$, or 33.3 students. This is the number the department is likely to publicize.

But once again, let's adopt the perspective of the average person and reexamine these numbers. Eighty of the 100 students find themselves in a class with 80 students, 15 find themselves in a class of 15 students, and five in a class of five students. Thus, the average student's class size is $(80 \times 80 + 15 \times 15 + 5 \times 5)/100$, or 66.5 students. This number is less likely to be publicized by the department.

Of course, the argument applies to many situations. Consider population density. The average number of human beings per square mile of the earth's land surface is low. Looked at from the perspective of the average human being, however, the density is much higher because most humans reside in cities. Thus, we can conclude that despite being more crowded together than average, most of us are less popular than average.

—John Allen Paulos

Paulos teaches mathematics at Temple University.

Katie Moisse is a New York–based health and science reporter and a former neuroscientist.

The YouTube Cure

Popular demand for an unproved surgical treatment for multiple sclerosis shows the growing power of social media to shape medical practice—for good and ill

When vascular surgeon Paolo Zamboni reported in December 2009 that inflating a tiny balloon inside twisted veins in the neck provided relief from multiple sclerosis, he created quite a stir. The idea that surgically straightening crooked veins could somehow benefit a degenerative nerve problem was astounding. Physicians were skeptical. Zamboni himself concluded that his findings should be subjected to more rigorous testing. Regardless, many people with MS, which affects at least 250,000 people in the U.S., immediately began clamoring for the unproved treatment. Their demands, amplified through a wide range of social-networking platforms, soon proved impossible to resist. In the past year, for instance, hospitals in California, New York, Italy and Poland have offered the Zamboni treatment—at a cost of $10,000 or more because it is not covered by insurance.

Doctors found themselves playing catch-up every step of the way. Even before Zamboni published his results in the *Journal of Vascular Surgery,* a post on PatientsLikeMe.com (an online patient community) boasted news of his research, useful links and a dedicated Facebook URL. Community networks traded contact information detailing who would offer the procedure and where. Before-and-after videos were posted on YouTube. Like AIDS activists of 30 years ago but armed with much more powerful communications tools, patients challenged researchers and medical centers to explain why it was taking so long to offer Zamboni's approach. Yet most MS experts believe that undergoing the procedure at the moment is a very risky proposition.

This episode highlights a growing challenge for patients: how to temper enthusiasm for experimental therapies, now widely and effectively marketed through personal testimonials posted online, until evidence shows that the treatments are likely to do more good than harm. "You can never blame people for being excited about something that sounds like good news, especially when they have a serious disease," says Aaron Miller, a professor of neurology at Mount Sinai School of Medicine and chief medical officer for the National MS Society. "I think these social-media sites can have a positive function in that they allow patients to discuss research and share their experiences." But, he adds, "they have a very major risk in leading patients to embark on therapeutic courses that are not necessarily appropriate for them or haven't been established as being scientifically valid."

A DANGEROUS GAME

In the case of Zamboni's work, it is easy to see how patients might be tempted to jump the gun and seek a treatment that initially sounds exciting. After all, the study findings came from a reputable surgeon (though not an MS researcher) publishing in a respected journal. As Daniel Simon, an interventional radiologist in Edison, N.J., says of the work: "It wasn't *Bob's Journal of MS and Autobody Repair;* it was the premier journal of vascular surgery."

It is also easy to see why racing to get treatment can be a dangerous game to play. In the first place, one study, even a well-done one, does not show that a therapy is ready for prime time. Often in medicine, early positive findings wash away later. And Zamboni himself pointed out that the study had limitations. The small trial was not randomized, double-blinded or placebo-controlled—the combination of which is considered the gold standard in clinical research. Participants also continued to take immune system–modulating therapies known to reduce symptoms.

In the case of MS, as with some other disorders, the difficulty of knowing whether a treatment that seemed to work really did

Illustration by Andrew Bannecker

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Please see additional important information on next page.

IMPORTANT SAFETY INFORMATION:
LIPITOR is not for everyone. It is not for those with liver problems. And it is not for women who are nursing, pregnant or may become pregnant.

If you take LIPITOR, tell your doctor if you feel any new muscle pain or weakness. This could be a sign of rare but serious muscle side effects. Tell your doctor about all medications you take. This may help avoid serious drug interactions. Your doctor should do blood tests to check your liver function before and during treatment and may adjust your dose.

Common side effects are diarrhea, upset stomach, muscle and joint pain, and changes in some blood tests.

INDICATION:
LIPITOR is a prescription medicine that is used along with a low-fat diet. It lowers the LDL ("bad" cholesterol) and triglycerides in your blood. It can raise your HDL ("good" cholesterol) as well. LIPITOR can lower the risk for heart attack, stroke, certain types of heart surgery, and chest pain in patients who have heart disease or risk factors for heart disease such as age, smoking, high blood pressure, low HDL, or family history of early heart disease.

LIPITOR can lower the risk for heart attack or stroke in patients with diabetes and risk factors such as diabetic eye or kidney problems, smoking or high blood pressure.

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch or call 1-800-FDA-1088.

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LIPITOR atorvastatin calcium tablets (LIP-ih-tore)

LOWERING YOUR HIGH CHOLESTEROL

High cholesterol is more than just a number, it's a risk factor that should not be ignored. If your doctor said you have high cholesterol, you may be at an increased risk for heart attack and stroke. But the good news is, you can take steps to lower your cholesterol.

With the help of your doctor and a cholesterol-lowering medicine like LIPITOR, along with diet and exercise, you could be on your way to lowering your cholesterol.

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WHO IS LIPITOR FOR?

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- Adults and children over 10

Who should NOT take LIPITOR:

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- Women who are breast-feeding. LIPITOR can pass into your breast milk and may harm your baby.
- People with liver problems
- People allergic to anything in LIPITOR

BEFORE YOU START LIPITOR

Tell your doctor:

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- If you have muscle aches or weakness
- If you drink more than 2 alcoholic drinks a day
- If you have diabetes or kidney problems
- If you have a thyroid problem

ABOUT LIPITOR

LIPITOR is a prescription medicine. Along with diet and exercise, it lowers "bad" cholesterol in your blood. It can also raise "good" cholesterol (HDL-C).

LIPITOR can lower the risk of heart attack, stroke, certain types of heart surgery, and chest pain in patients who have heart disease or risk factors for heart disease such as:

- age, smoking, high blood pressure, low HDL-C, family history of early heart disease

LIPITOR can lower the risk of heart attack or stroke in patients with diabetes and risk factors such as diabetic eye or kidney problems, smoking, or high blood pressure.

POSSIBLE SIDE EFFECTS OF LIPITOR

Serious side effects in a small number of people:

- **Muscle problems** that can lead to kidney problems, including kidney failure. Your chance for muscle problems is higher if you take certain other medicines with LIPITOR.
- **Liver problems**. Your doctor may do blood tests to check your liver before you start LIPITOR and while you are taking it.

Call your doctor right away if you have:

- Unexplained muscle weakness or pain, especially if you have a fever or feel very tired
- Allergic reactions including swelling of the face, lips, tongue, and/or throat that may cause difficulty in breathing or swallowing which may require treatment right away
- Nausea, vomiting, or stomach pain
- Brown or dark-colored urine
- Feeling more tired than usual
- Your skin and the whites of your eyes turn yellow
- Allergic skin reactions

Common side effects of LIPITOR are:

- Diarrhea
- Upset stomach
- Muscle and joint pain
- Changes in some blood tests

HOW TO TAKE LIPITOR

Do:

- Take LIPITOR as prescribed by your doctor.
- Try to eat heart-healthy foods while you take LIPITOR.
- Take LIPITOR at any time of day, with or without food.
- If you miss a dose, take it as soon as you remember. But if it has been more than 12 hours since your missed dose, wait. Take the next dose at your regular time.

Don't:

- Do not change or stop your dose before talking to your doctor.
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- Do not give your LIPITOR to other people. It may harm them even if your problems are the same.
- Do not break the tablet.

NEED MORE INFORMATION?

- Ask your doctor or health care provider.
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- Go to **www.lipitor.com** or call **1-888-LIPITOR**.

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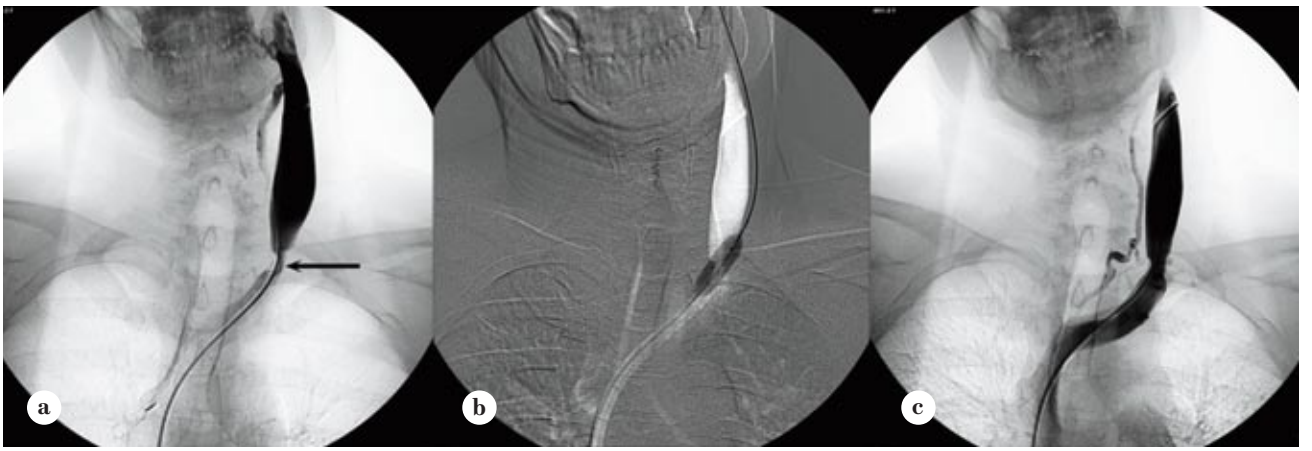

Test case: Vascular surgeon Zamboni snaked a catheter through the body to a narrowed passage (*arrow*) in a jugular vein. He inflated a balloon (*b*) to open up the vein and restored normal blood flow (*c*). Whether the procedure helps MS patients is unproved.

have an effect in a study is compounded by the erratic nature of the disease. The most common form—relapse-remitting MS—has a variable course marked by flare-ups amid symptom-free periods. So it is difficult to know if a certain treatment actually works or was simply taken during a naturally occurring remission. Patients taking placebo have often reported substantial improvements, according to Mount Sinai's Miller.

Furthermore, the ultimate cause of the disease remains obscure, which makes it hard to gauge the appropriateness of an intervention. Everyone agrees that MS destroys the fatty myelin sheath that enwraps many nerve fibers. Stripped of their insulation, the wires of the nervous system lose their ability to transmit the electrical signals needed for movement, sensation and vision. Most researchers assume some kind of autoimmune response, in which a person's own defense system attacks rather than ignores the body's own tissues, is at work.

Given that current MS treatments are a far cry from a cure and do not work for everyone, some people with MS feel there is no harm in trying something that might improve their quality of life. The answer, of course, is that it could also make their quality of life much, much worse. Any surgery carries the risk of infection, and the procedure itself can actually damage the blood vessels, making them more vulnerable to clots and aneurysms.

Without more rigorous clinical trials, it is almost impossible to weigh accurately the potential costs and benefits. The operation to straighten out and puff up crooked and collapsed veins, called venoplasty, is almost identical to cardiac angioplasty—a common treatment for diseased coronary arteries. (Side effects for both include blood clots, infections and severe internal bleeding.) After piercing through a vein in the pelvis, a spaghetti-size catheter is threaded up through a vein near the spine and into the neck, where a balloon on the catheter's tip is inflated to pop the neck vein back to its normal shape—just like squatting in jeans that have shrunk in the wash stretches them, Simon explains.

But veins, which are more pliable than arteries, often regain their tortuous shape within months after venoplasty, requiring multiple procedures. One MS patient in the U.S. reportedly died from a brain hemorrhage while recovering, and another needed emergency surgery after a stent implanted to permanently straighten a vein dislodged and migrated to the heart.

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/feb2011

READY FOR TESTING

One thing in favor of Zamboni's approach is it has a reasonable scientific rationale, which not all potential therapies touted on the Internet have. A close look at the characteristic plaques of scar tissue that lend the disease its name shows that they typically cluster around blood vessels. And that, Zamboni says, is key. Veins are flexible and can get twisted, slowing the rate of blood flow and potentially leaving waste and compounds such as iron to accumulate in the brain. Isn't it possible, he wonders, the buildup triggers an inflammatory response? And if the inflammation lasted long enough, it could eventually end up targeting the myelin wrapping of the nerves. A similar mechanism had been linked to myelopathies, degenerative conditions of the spinal cord, which bear a pathological semblance to MS.

That is a lot of "if's." But some physicians consider Zamboni's hypothesis and treatment plausible enough to test. And the National MS Society and the Multiple Sclerosis Society of Canada have pledged $2.4 million over the next two years to examine the role that problems with venous circulation might play in multiple sclerosis. "There is little doubt that the intense interest in [venoplasty for MS] played a role in the decisions by the National MS Society and the Canadian MS Society to fund further research," Miller says. Still, it is just too soon, he believes, to offer the procedure unless it is a part of a clinical trial.

A lesson from this episode, Miller says, is that it is important for neurologists and other physicians to be aware of what patients are seeing and reading online. "We can't bury ourselves in an ivory tower and function as though [social-media sites] don't exist," he notes. "What our patients are thinking, we need to address. We have to be aware of it and be prepared to discuss it with them logically." Miller says his patients almost invariably have been able to engage with him. After he explains the lack of certainty about venoplasty for MS, he observes, they usually agree with his advice to wait. Just how long they will continue to do so, however, may depend a lot on what social media push next. SA

FROM "A PROSPECTIVE OPEN-LABEL STUDY OF ENDOVASCULAR TREATMENT OF CHRONIC CEREBROSPINAL VENOUS INSUFFICIENCY," BY PAOLO ZAMBONI ET AL., IN *JOURNAL OF VASCULAR SURGERY*, VOL. 50, NO. 6, DECEMBER 2009

David Pogue is the personal-technology columnist for the *New York Times* and host of the new science miniseries *Making Stuff* on PBS.

An Open Question

The success of Google's Android software doesn't prove that open is better

According to conventional wisdom, Apple blew its first chance to dominate the computer industry. It missed out on becoming the 800-pound PC gorilla because its systems were too closed. Not just in the literal sense—the original Macintosh computers were sealed tight, so tinkerers couldn't fool around with the guts—but in the licensing sense. That is, only Apple could make computers running the Mac operating system. Microsoft, on the other hand, licensed Windows to any old computer company—and today Windows runs 90 percent of the world's PCs.

But then, a few years later, a second experiment ran, this time involving music players. Here again, both Apple and Microsoft used precisely the same playbooks they had with computers. In this corner: Steve Jobs, insisting on being the sole creator of both the iPod and its software. In that corner: Microsoft, offering its music-player software platform, called PlaysForSure, to any company that paid the licensing fee.

This time the results were reversed. The proprietary model triumphed—big time. The iPod gobbled up 85 percent of the music-player market. And Microsoft? It took PlaysForSure out behind the barn and shot it.

(Microsoft then ran a third experiment. It introduced a completely new music-player system, called Zune, modeled, incredibly, on Apple's closed-architecture model. It failed, too.)

So we have several controlled studies with contradictory results. Which is the right approach? To license? Or to control?

Now we are engaged in a great market war, testing which model assures market dominance. It is the biggest test yet: the app-phone battle. This time the war is between Apple (iPhone, proprietary) and Google (Android, open).

Once again, Apple's approach is to let only Apple make the hardware and software. Nobody else makes iPhones. Google, on the other hand, is taking the Microsoft "anyone can use our software" principle and running with it. Its Android phone software is not only open, it's free. Any company can make an app phone (or tablet or e-book reader) using Android, without paying Google anything, and even make changes to it.

So far the experiment is shaping up magnificently. Companies all over the globe are pumping out Android phones—30 million and counting. Apple has sold 75 million iPhones, but it had a year's head start on Google.

That makes Android a fantastic success, but as an experiment, this one is poorly designed. The question is: How much of Android's appeal is its openness?

Truth is, you could argue that "open" makes the customer's life miserable. It means that AT&T or Verizon can junk up your new phone with icons for their own ugly, overpriced add-on services. (Apple would never dream of letting third parties preinstall junkware on an iPhone.)

Worse, open also means that there isn't one Android. It becomes a splintered platform of slightly modified versions. Just ask any owner of an Android phone who was excited by the possibility of playing Flash videos when Adobe finally released the necessary Android plug-in—and found that it would run only on a handful of Android models.

Google's app store is more open than Apple's, too; Apple, notoriously, employs human editors to approve each app individually. Among other things, that means that you can get porn apps on an Android phone but not an iPhone. But that also means that Apple's store is better organized and higher quality than Google's chaotic Android marketplace.

This is going to sound radical. But could it be that "open" is a great big fat red herring?

From the perspective of phone makers, is the openness really the attraction to Android? Or could it be that the greater draw is that Android is a complete, polished, elegant phone OS with built-in software library—and it doesn't cost the phone maker a penny?

And from the consumer's perspective, does the openness really matter? Has anyone ever marched into a Verizon store and said, "I want a Droid phone because I want to make cosmetic changes to Android" instead of "I want a Droid phone because it's thin, fast and runs on Verizon"?

Maybe what the world needs is one final grand scientific experiment: closed and proprietary (Apple) versus closed and free (Google). You know—somehow separate the variables "free" and "modifiable," so we can see more clearly what's responsible for Android's momentum.

Okay, that experiment isn't going to happen. But that's the only way to know the real value of "open." SA

ESSENTIAL APPS FOR IPHONE AND ANDROID
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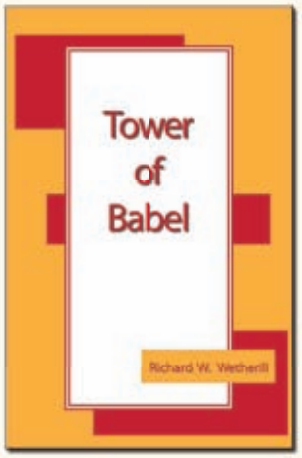
Illustration by Leo Espinosa

Nature's Formula For Success Works For Everybody With The Courage To Pioneer.



Nature's Formula is found in a natural law of behavior identified by the late Richard W. Wetherill early in the past century and presented in his book, *Tower of Babel*. He called it nature's ***law of absolute right. It states: Right Action Gets Right Results; Wrong Action Gets Wrong Results.***

Tower of Babel was published January 2, 1952, but very few people showed interest. So during those past decades, untold numbers of problems and trouble have continued to plague the human race.

Wetherill's book describes the ***causative factor of those problems, explains what is blocking people's awareness of that factor, and how to overcome it***.

Clearly, mankind's teachings of right and wrong action have failed to produce a trouble-free society. Quite the opposite, mankind's teachings are producing worldwide mayhem. The reason is that none of mankind's various definitions of right and wrong action conform to nature's definitions of right and wrong action. ***The behavioral law defines right action as decisions and behavior that are rational and honest, and it defines wrong action as decisions and behavior that do not comply with the criteria of this natural law.***

Just as creation's laws of physics apply indiscriminately to everybody everywhere so, too, does nature's law of behavior. Until people think and act in accord with that law, their wrong results will continue.

Wetherill called his findings *humanetics*, and in the 1970s he formed a research group of ordinary people who were able to make impressive changes. They formed a business that became the major supplier of its industry, doing global sales of more than $200 million. They formed a private school and taught students the principles of the law's right action. Their teachers reported that improvements in the pupils' scholastic abilities and behavior were dramatic.

Clearly, ***nature's formula for success depends on people's continued adherence to the law's definition of right action***.

Wetherill taught the researchers not to *believe* what he said but to let his words direct their attention to the ***reality*** being described so that reality could confirm or deny what had been said. When confirmed, information becomes ***knowledge***. When denied, information remains ***hearsay***.

People tend not to understand ***nature's formula for success*** just by reading about it. They need to see its correctness in the reality of life. ***Reality is not written on paper. Reality is written in life***.

A research scientist has said, "The brain, more than any other organ, is where experience becomes flesh." With the intent to do what is right, applying ***nature's formula for success*** directs thinking steadfastly to the rational, honest behavior that reality calls for, thus releasing the flesh of wrong brain circuits. When released from that influence, people are free to think, say, and do what accords with nature's behavioral law.

As one of America's Founding Fathers, Benjamin Franklin, had said, *"Only virtuous people are capable of freedom."* People who reason from nature's law of absolute right enjoy that freedom.

Visit our Website www.alphapub.com where essays and books (including Tower of Babel) describe the changes called for by nature's law of absolute right. The material can be read, downloaded, and/or printed FREE. If you lack access to the Website, our books are also available in print at low cost. For an order form, write to The Alpha Publishing House, 677 Elm St, Ste 112, PO Box 255, Royersford, PA 19468.

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

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

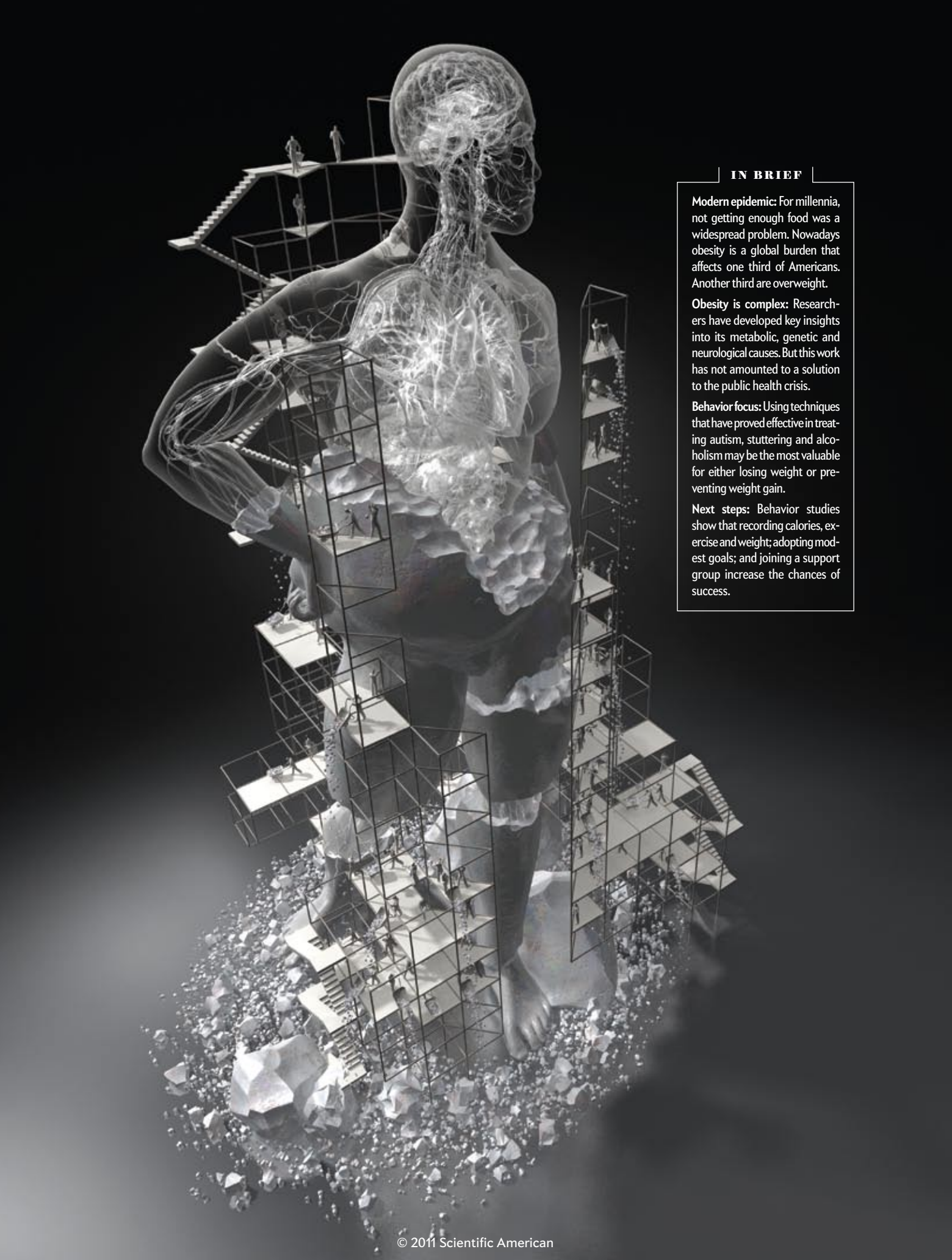
HEALTH

How to fix the obesity crisis

Although science has revealed a lot about metabolic processes that influence our weight, the key to success may lie elsewhere

By David H. Freedman

Illustration by Bryan Christie



IN BRIEF

Modern epidemic: For millennia, not getting enough food was a widespread problem. Nowadays obesity is a global burden that affects one third of Americans. Another third are overweight.

Obesity is complex: Researchers have developed key insights into its metabolic, genetic and neurological causes. But this work has not amounted to a solution to the public health crisis.

Behavior focus: Using techniques that have proved effective in treating autism, stuttering and alcoholism may be the most valuable for either losing weight or preventing weight gain.

Next steps: Behavior studies show that recording calories, exercise and weight; adopting modest goals; and joining a support group increase the chances of success.

OBESITY IS A NATIONAL HEALTH CRISIS—THAT MUCH we know. If current trends continue, it will soon surpass smoking in the U.S. as the biggest single factor in early death, reduced quality of life and added health care costs. A third of adults in the U.S. are obese, according to the Centers for Disease Control and Prevention, and another third are overweight, with Americans getting fatter every year. Obesity is responsible for more than 160,000 "excess" deaths a year, according to a study in the *Journal of the American Medical Association*. The average obese person costs society more than $7,000 a year in lost productivity and added medical treatment, say researchers at George Washington University. Lifetime added medical costs alone for a person 70 pounds or more overweight amount to as much as $30,000, depending on race and gender.

All this lends urgency to the question: Why are extra pounds so difficult to shed and keep off? It doesn't seem as though it should be so hard. The basic formula for weight loss is simple and widely known: consume fewer calories than you expend. And yet if it really were easy, obesity would not be the nation's number-one lifestyle-related health concern. For a species that evolved to consume energy-dense foods in an environment where famine was a constant threat, losing weight and staying trimmer in a modern world of plenty fueled by marketing messages and cheap empty calories is, in fact, terrifically difficult. Almost everybody who tries to diet seems to fail in the long run—a review in 2007 by the American Psychological Association of 31 diet studies found that as many as two thirds of dieters end up two years later weighing *more* than they did before their diet.

Science has trained its big guns on the problem. The National Institutes of Health has been spending nearly $800 million a year on studies to understand the metabolic, genetic and neurological foundations of obesity. In its proposed plan for obesity research funding in 2011, the NIH lists promising research avenues in this order: animal models highlighting protein functions in specific tissues; complex signaling pathways in the brain and between the brain and other organs; identification of obesity-related gene variants; and epigenetic mechanisms regulating metabolism.

This research has provided important insights into the ways proteins interact in our body to extract and distribute energy from food and produce and store fat; how our brains tell us we are hungry; why some of us seem to have been born more likely to be obese than others; and whether exposure to certain foods and toxic substances might modify and mitigate some of these factors. The work has also given pharmaceutical companies numerous potential targets for drug development. What the research has not done, unfortunately, is make a dent in solving the national epidemic.

Maybe someday biology will provide us with a pill that readjusts our metabolism so we burn more calories or resets our built-in cravings so we prefer broccoli to burgers. But until then, the best approach may simply be to build on reliable behavioral-psychology methods developed over 50 years and proved to work in hundreds of studies. These tried-and-true techniques, which are being refined with new research that should make them more effective with a wider range of individuals, are gaining new attention. As the NIH puts it in its proposed strategic plan for obesity research: "Research findings are yielding new and important insights about social and behavioral factors that influence diet, physical activity, and sedentary behavior."

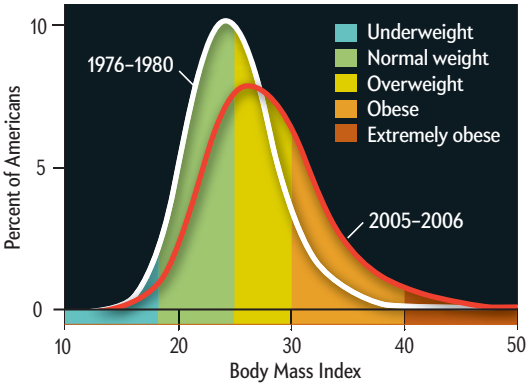
HOW WE GOT HERE

THE DESPERATION OF THE OBESE AND OVERWEIGHT is reflected in the steady stream of advice pouring daily from sources as disparate as peer-reviewed scientific journals, best-selling books, newspapers and blogs. Our appetite for any diet twist or gimmick that will take the pounds off quickly and for good seems to be

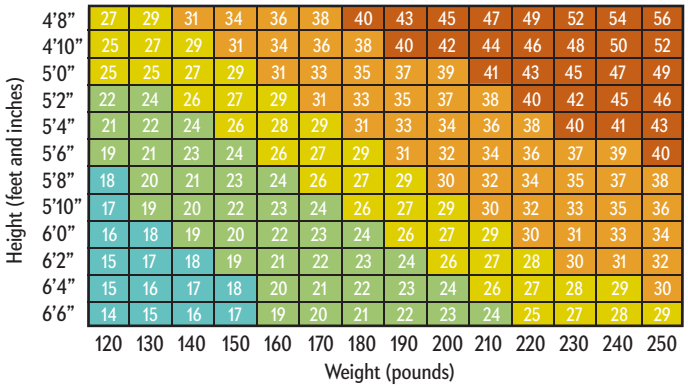
OBESITY EPIDEMIC

A Growing Problem

Increases in overweight and obesity in the U.S. (*left*), as measured by the body mass index (*right*), presage a growing burden of stroke, heart disease, type II diabetes, some types of cancer and other chronic health problems throughout the 21st century.



Getting bigger: Just over 34 percent of American adults are obese (*orange area under curve*)—up from 15 percent in the late 1970s. Thirty-three states have obesity rates over 25 percent (*not shown*).



Body mass index is a ratio of height to weight, developed by 19th-century Belgian mathematician and proto-sociologist Adolphe Quetelet. Although BMI does not measure body fat, anyone (except very muscular athletes) with a number over 30 is considered obese.

SOURCES: CDC/NCHS, NATIONAL HEALTH AND NUTRITION EXAMINATION SURVEY (*BMI changes*); NATIONAL OBESITY EDUCATION INITIATIVE (*BMI chart*)

Graphics by Jen Christiansen

as insatiable as our appetite for the rich food that puts the pounds on. We, the public, love to believe in neat fixes, and the media oblige by playing up new scientific findings in headline after headline as if they are solutions.

It doesn't help that the scientific findings on which these headlines are based sometimes appear to conflict. For example, a study in September's *American Journal of Clinical Nutrition* found a link between increased dairy intake and weight loss, although a meta-analysis in the May 2008 *Nutrition Reviews* discovered no such link. A paper in the *Journal of Occupational and Environmental Medicine* in January 2010 postulated a connection between job stress and obesity, but in October a report in the journal *Obesity* concluded there was no such correlation. Part of the problem, too, is that obesity researchers are in some ways akin to the metaphorical blind men groping at different parts of the elephant, their individual study findings addressing only narrow pieces of a complex puzzle.

When the research is taken together, it is clear that the obesity fix cannot be boiled down to eating this or that food type or to taking any other simple action. Many factors contribute to the problem. It is partly environment—the eating habits of your friends, what food is most available in your home and your local stores, how much opportunity you have to move around at work. It is partly biology—there are genetic predispositions for storing fat, for having higher satiety thresholds, even for having more sensitive taste buds. It is partly economics—junk food has become much cheaper than fresh produce. And it is marketing, too—food companies have become masterful at playing on human social nature and our evolutionary "programming" to steer us toward unhealthy but profitable fare. That is why the narrow "eat this" kinds of solutions, like all simple solutions, fail.

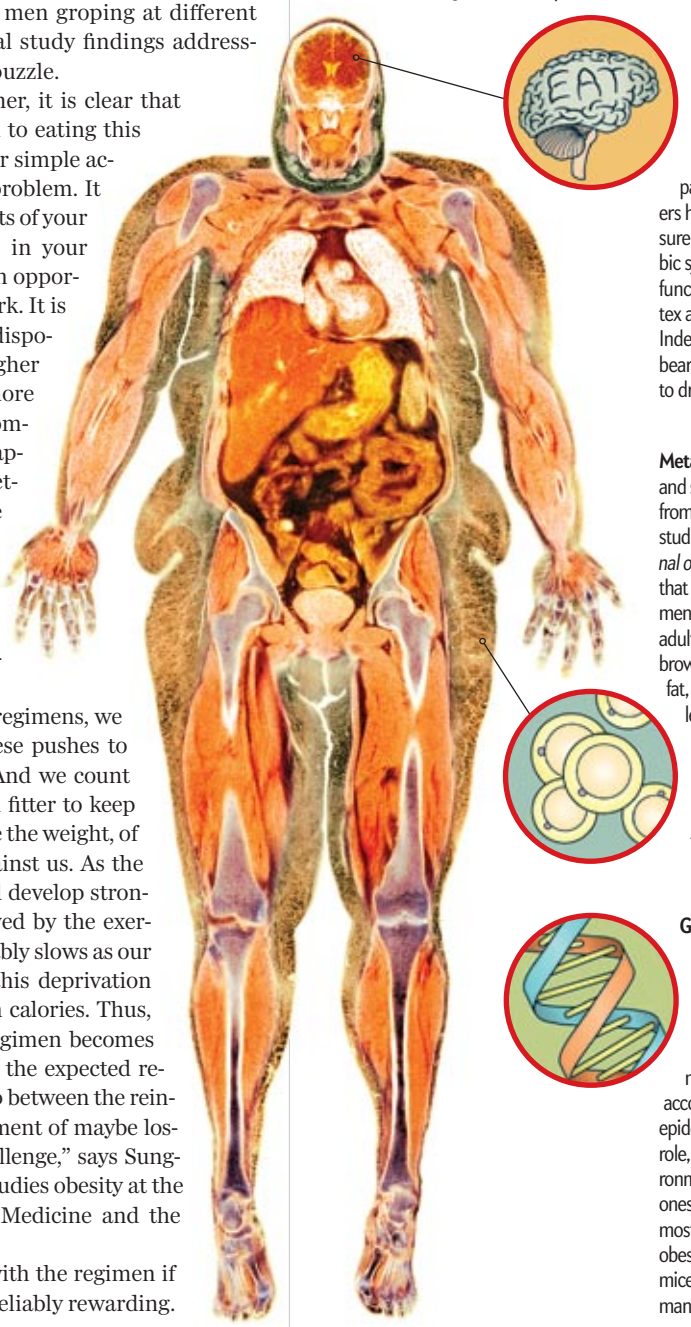
When we go on diets and exercise regimens, we rely on willpower to overcome all these pushes to overeat relative to our activity level. And we count on the reward of getting trimmer and fitter to keep us on the wagon. It *is* rewarding to lose the weight, of course. Unfortunately, time works against us. As the weight comes off, we get hungrier and develop stronger cravings and become more annoyed by the exercise. Meanwhile the weight loss inevitably slows as our metabolism tries to compensate for this deprivation by becoming more parsimonious with calories. Thus, the punishment for sticking to our regimen becomes increasingly severe and constant, and the expected reward recedes into the future. "That gap between the reinforcement of eating and the reinforcement of maybe losing weight months later is a huge challenge," says Sung-Woo Kahng, a neurobehaviorist who studies obesity at the Johns Hopkins University School of Medicine and the Kennedy Krieger Institute.

We would be more likely to stick with the regimen if it remained less punishing and more reliably rewarding. Is there a way to make that happen?

ADVANCES IN THE LAB

The Biology of Obesity

The National Institutes of Health has spent nearly $800 million a year on studies to understand the neurological, metabolic and genetic foundations of obesity. In the process, scientists have uncovered complex biochemical pathways and feedback loops that connect the brain and digestive system; a new appreciation for the regulatory functions of fat tissues; subtle hereditary changes that make some groups more prone to obesity than others; and the strong possibility that exposure to certain foods and toxic substances might modify and mitigate some of these factors. Given that it will likely take decades to understand the various causes of obesity, more surprises are no doubt in store.



Brain: Scientists have long known that the hypothalamus and brain stem help to regulate feelings of hunger and fullness. Over the past several years researchers have found that the pleasure-reward centers of the limbic system and the evaluating functions of the prefrontal cortex are also heavily involved. Indeed, chronic overeating bears biochemical similarities to drug addiction.

Metabolism: The ability to burn and store energy varies greatly from cell to cell. In 2009 three studies in the *New England Journal of Medicine* demonstrated that at least some women and men continue to benefit well into adulthood from small stores of brown fat, which, unlike white fat, is associated with being lean. Brown fat helps to generate heat and is apparently more closely related to muscle than to white fat, whose primary purpose is to store excess energy.

Genes: Researchers have confirmed variations in 20-odd genes that predispose people to gaining weight easily. But further investigation shows that the effects are modest at best and cannot account for the current obesity epidemic. Genes may still play a role, however, through the environment's influence on which ones get turned on or off. So far most such genetic switches for obesity have been identified in mice, although a few likely human candidates are known.

PHOTO RESEARCHERS, INC. (*MRI*)

Illustration by Peter and Maria Hoey

FROM BIOLOGY TO BRAIN

THE MOST SUCCESSFUL WAY to date to lose at least modest amounts of weight and keep it off with diet and exercise employs programs that focus on changing behavior. The behavioral approach, tested over decades, involves making many small, sustainable adjustments in eating and exercise habits that are prompted and encouraged by the people and the rest of the environment around us.

The research in support of behavioral weight-loss approaches extends back more than half a century to Harvard University psychologist B. F. Skinner's development of the science of behavioral analysis. The field is founded on the notion that scientists cannot really know what is going on inside a person's brain—after all, even functional MRIs, the state of the art for peering into the mind, are crude, highly interpretable proxies for cognition and emotion that reduce the detailed firing of billions of neurons in complex circuits to a few blobs of color. But researchers can objectively and reproducibly observe and measure physical behavior and the immediate environment in which the behavior occurs, allowing them to identify links between environment and behavior. That typically includes trying to spot events or situations that may be prompting or triggering certain behaviors and noting what may be rewarding and thus reinforcing of some behaviors or punishing and thus inhibiting of others.

Mass-market programs tend to fall short when it comes to enlisting a full range of behavioral techniques and customizing them to meet the varied needs of individuals.

The effectiveness of behavioral interventions has been extensively documented for a wide variety of disorders and problem behaviors. A 2009 meta-analysis in the *Journal of Clinical Child & Adolescent Psychology* concluded that "early intensive behavioral intervention should be an intervention of choice for children with autism." A systematic review sponsored by the U.S. Preventive Services Task Force found that even brief behavioral counseling interventions reduced the number of drinks taken by problem drinkers by 13 to 34 percent for as long as four years. Review studies have found similar behavioral-intervention successes in challenges as diverse as reducing stuttering, increasing athletic performance and improving employee productivity.

To combat obesity, behavioral analysts examine related environmental influences: Which external factors prompt people to overeat or to eat junk food, and which tend to encourage healthful eating? In what situations are the behaviors and comments of others affecting unhealthful eating? What seems to effectively reward eating healthfully over the long term? What reinforces being active? Behavior-focused studies of obesity and diets as early as the 1960s recognized some basic conditions that seemed correlated with a greater chance of losing weight and keeping it off: rigorously measuring and recording calories, exercise and weight; making modest, gradual changes rather than severe ones; eating balanced diets that go easy on fats and sugar rather than dropping major food groups; setting clear, modest goals; focusing on lifelong habits rather than short-term diets; and especially attending groups where dieters could receive encouragement to stick with their efforts and praise for having done so.

If these strategies today sound like well-worn, commonsense advice, it is because they have been popularized for nearly half a century by Weight Watchers. Founded in 1963 to provide support groups for dieters, Weight Watchers added other approaches and advice in keeping with the findings of behavioral studies and used to bill itself as a "behavior-modification" program. "Whatever the details are of how you lose weight, the magic in the sauce is always going to be changing behavior," says nutrition researcher and Weight Watchers chief science officer Karen Miller-Kovach. "Doing that is a learnable skill."

Studies back the behavioral approach to weight loss. A 2003 review commissioned by the U.S. Department of Health and Human Services found that "counseling and behavioral interventions showed small to moderate degrees of weight loss sustained over at least one year"—a year being an eon in the world of weight loss. An analysis of eight popular weight-loss programs published in 2005 in the *Annals of Internal Medicine* found Weight Watchers (at that time in its pre-2010 points-overhaul incarnation) to be the only effective program, enabling a 3 percent maintained body-weight loss for the two years of the study. Meanwhile a 2005 *JAMA* study found that Weight Watchers, along with the Zone diet (which, like Weight Watchers, recommends a balanced diet of protein, carbohydrates and fat), achieved the highest percentage (65 percent) of one-year diet adherence of several popular diets, noting that "adherence level rather than diet type was the key determinant of clinical benefits." A 2010 study in the *Journal of Pediatrics* found that after one year children receiving behavioral therapy maintained a body mass index that was 1.9 to 3.3 lower than children who did not. (BMI is a numerical height-weight relation in which 18.5 is held to be borderline underweight and 25 borderline overweight.) The *Pediatrics* report noted that "more limited evidence suggests that these improvements can be maintained over the 12 months after the end of treatments." A 2010 study in *Obesity* found that continuing members of Take Off Pounds Sensibly (TOPS), a national, nonprofit behaviorally focused weight-loss organization, maintained a weight loss of 5 to 7 percent of their body weight for the three years of the investigation. The U.K.'s Medical Research Council last year declared that its own long-term study had shown that programs based on behavioral principles are more likely to help people take and keep the weight off than other approaches. (The study was funded by Weight Watchers, but without its participation.)

But Weight Watchers and other mass-market programs tend to fall short when it comes to enlisting a full range of behavioral techniques and customizing them to meet the varied needs of individuals. They cannot routinely provide individual counseling, adapt their advice to specific challenges, assess environmental factors in a member's home, workplace or community, provide much outreach to members who do not come to meetings, or prevent their members from shooting for fast, dramatic, short-term weight loss or from restricting food groups. As a for-profit company, Weight Watchers sometimes even mildly panders to these self-defeating notions in its marketing. "Some people join us to drop 10 pounds for a high school reunion," says Weight Watchers's Miller-Kovach. "They achieve that goal, then stop coming."

To close that gap, a number of researchers have turned their attention in recent years to improving, expanding and tailoring behavioral techniques, with encouraging results. For example, Michael Cameron, head of the graduate behavioral analysis department at Simmons College and a faculty member at Harvard Medical School, is now focusing his research on behavioral weight-loss techniques. He is one year into a four-person study—behavioral analysts generally do very small group or even single-subject studies to more closely tailor the intervention and observe individual effects—in which the subjects meet together with him via online videoconferencing for reinforcement, weigh themselves on scales that transmit results via wireless networks, and have their diets optimized to both reduce caloric density and address individual food preferences. Favorite foods are used as a reward for exercise. So far the subjects have lost between 8 and 20 percent of their body weight.

Matt Normand, a behavioral analyst at the University of the Pacific, has focused on finding ways to more precisely track subjects' calorie intake and expenditure by, for example, collecting receipts for food purchases, providing food checklists to record what is eaten, and enlisting various types of pedometers and other devices for measuring physical activity. He then provides participants with daily detailed accounts of their calorie flow and in one published study showed three of four subjects reduced calorie intake to recommended levels. Richard Fleming, a researcher at the University of Massachusetts Medical School's Shriver Cen-

WHAT WORKS?

Four Steps to Losing Weight

Behavior-focused studies of obesity and diets have identified some basic conditions that seem correlated with a greater chance of losing weight and keeping it off: setting clear, modest goals and focusing on lifelong habits, among others. Most of these behavior changes fall into four main categories.

Initial Assessment

Research underscores the need to determine baseline measurements. How much does an individual weigh? What rituals and routines contribute to overeating (eating under stress) or underexercising (unrealistic expectations)? A physician, a nurse practitioner or a nutrition counselor can help with the assessment.

Behavior Shifts

Many people find it is easier to make small changes at first—such as taking the stairs instead of an elevator. Studies show that surveying the entire buffet before serving themselves will help people put less food on their plates.

Self-Monitoring

Recording body weight, counting the calories eaten and logging steps taken provide objective feedback on how well individuals are changing their habits. Behavior studies have found both low-tech paper logs and wireless monitoring systems to be of benefit.

Support Groups

Studies document the benefits of encouragement by others. Being part of a group—whether an exercise group, a formal support group or even a virtual group—lets participants share triumphs, bemoan setbacks and strategize solutions.

Illustration by Peter and Maria Hoey

A Healthier Urban Jungle

New York City is using policy and economics to improve its "food environment"

By Thomas Farley

A RESEARCHER ONCE told me that progress in biomedical science could be measured by the ever shrinking size of our focus. Long ago we understood only the differences between sick and healthy individuals, but now we have zoomed through organs and cells into studying sick and healthy molecules. This type of thinking has led some to search for the solution to the national epidemic of obesity within our body's cells.

They won't find it there. We will reverse this epidemic not with a better microscope but rather with a better macroscope—not through genetics or physiology but through sociology and economics. In New York City, where we must reach millions of people who are overweight or headed there, we are using public policy and economic incentives to create a healthier food environment.

Eating is individual behavior, so why should we focus on the environment instead of educating people to make better choices? The simple answer is that people haven't changed over the past three decades. We're the same creatures we were in the 1970s, but the world we inhabit has changed radically.

Food is now ubiquitous, cheap, calorie-dense, and delivered to us in superphysiologic portion sizes. While there has been much talk of "food deserts" and their shortage of healthy foods in low-income neighborhoods, in fact most of us live in food swamps, where we drown in food laden with excess calories. Today it is hard to imagine a building without a soda vending machine or an intersection without a fast-food outlet. At bodegas in the South Bronx, the most prominent shelf items are three-liter bottles of soda, selling for $2 each, and huge bags of chips. Those chips pack about five calories per gram, which is more than 10 times the calorie density of a carrot.

It is far easier to describe this "obesogenic" food environment than to change it for the better. But in New York City we have been trying to nudge the system toward offering a healthier mix of products in human-size portions. We provide "Health Bucks"—$2 vouchers to use at farmers' markets—to people in the Supplemental Nutrition Assistance Program, or SNAP (formerly known as food stamps), as an incentive to buy low-calorie-density fresh fruits and vegetables. We encourage bodega operators to stock lower-calorie foods, and we have adopted zoning and financial incentives to draw supermarkets into neighborhoods that have nothing but bodegas. We are also improving the quality of foods sold in school cafeterias, while removing calorie-dense beverages from school vending machines. And we have established nutrition standards for foods sold or distributed by all city agencies, which together deliver some 225 million meals every year.

In 2008 New York City started requiring chain restaurants to post the calorie counts on their menus and menu boards. The immediate effect has been modest: about 25 percent of customers who see the calorie counts use them in choosing what to buy, and those who do so purchase about 100 fewer calories per meal. The greater potential payoff is that restaurants, ashamed to post a count of more than 1,000 calories for a sandwich, may reduce their portion sizes.

Any effort to create a healthier food environment must address sugar-sweetened beverages, which account for a third to a half of the 300-calorie increase in Americans' daily diets over the past 30 years. Sugar-sweetened drinks have been linked to obesity or weight gain in both observational studies and randomized clinical trials. New York City has supported state legislation that would balance the incentives to supersize by placing a penny-per-ounce excise tax on sugary drinks. Economic models suggest that a 10 percent increase in price would reduce the sale of these beverages by about 8 percent.

Choices: About 25 percent of customers who see calorie counts on restaurant menus use them in deciding what to buy and purchase about 100 fewer calories per meal.

Last fall New York City proposed a demonstration project to test the effect of ending the subsidy of sugar-sweetened products in the SNAP program. The measure would address a basic contradiction in public policy. When we are telling New Yorkers in every possible way that sugar-sweetened beverages cause obesity and diabetes, how can we justify giving vouchers to get these products for free, especially as part of a nutrition program? Our initiative could also change incentives in the market. If bodegas cannot sell three-liter bottles of sugary soda through the SNAP program, maybe they will promote something healthier that is SNAP-eligible.

Surveys that we have conducted show that adults have cut back somewhat on sugar-sweetened beverages since 2007. Those same surveys track self-reported height and weight in adults, and we actively monitor fitness and body mass index among the city's 1.2 million public school students. It is far too early to know if the changes we have made are affecting obesity rates. We are more than 30 years into this epidemic, and reversing it will take more than a few. But we believe we have found the right target. Unless our vision of a brighter future is a majority of Americans taking an antiobesity pill every day, it is our environment that needs to change, not our physiology.

Thomas Farley, M.D., M.P.H., is New York City's Health Commissioner.

STEPHEN CHERNIN *Getty Images*

ter, has in *Obesity* looked at ways to encourage parents to steer their children to healthier choices. He has found, among other techniques, that showing parents in person what appropriate serving sizes of foods look like on plates is helpful. Another successful Fleming trick: letting children pick out a small treat at a food store—as long as they walk there. "Kids can really respond to that reward for being active," he says.

Why are behavioral interventions effective? Laurette Dubé, a lifestyle psychology and marketing researcher at McGill University's Faculty of Management, notes that our environment is currently one in which ubiquitous, sophisticated marketing efforts prey on our need for sensory gratification as well as our vulnerability to misinformation. In addition, the poor eating and exercise habits we observe in our friends, family and colleagues encourage us to follow suit. In essence, behavioral interventions seek to reconfigure this environment into one in which our needs for information, gratification and social encouragement are tapped to pull us toward healthy food and exercise choices rather than away from them. "When we are getting the right messages in enough ways, we have a better chance of resisting the urge to eat more than we need," Dubé says.

Our environment is one in which ubiquitous, sophisticated marketing efforts prey on our need for sensory gratification as well as our vulnerability to misinformation.

CHANGING POLICY

THERE IS NO ONE-SIZE-FITS-ALL solution, behavioral or otherwise, to the problem of obesity. But although behavioral interventions work best when they are customized to individuals, mass-market behavioral approaches such as Weight Watchers and TOPS are at least fairly effective. Why don't more people lose weight with them? The main reason is that people simply do not sign up for them, often because would-be weight losers are chasing fad diets or supplements or have read that obesity is locked into our genes. Weight Watchers, by far the most popular behavioral weight-loss program, counts only 600,000 meeting-attending members in its ranks in North America. That means that fewer than one out of 100 obese people in the U.S. and about one out of 200 overweight people are part of a formal behavioral-modification program.

TAKE OUR WEIGHT-LOSS POLL
ScientificAmerican.com/feb2011/obesity-poll

Public policy may be changing, however. The U.S. Surgeon General's office and the CDC have both publicly lined up behind behavioral approaches as the main weapon in what is becoming a war on obesity. First Lady Michelle Obama's high-profile Let's Move campaign against childhood obesity consists almost entirely of behavioral weight-loss wisdom—that is, find ways to encourage children to eat less-calorie-dense foods, to become more active, and to enjoy doing it. The recent proposed ban of toys in Happy Meals in San Francisco suggests that more officials may be getting ready to pressure the food industry into easing up on contaminating the environment with what are essentially obesity-supportive marketing tactics. To make it easier and more tempting to buy healthier food in poorer, disproportionately overweight communities, the White House has proposed subsidizing the costs of fruits and vegetables. Approaching the problem from the other direction, New York City Mayor Michael Bloomberg is among those who have advocated modifying food-assistance programs to restrict the purchase of high-sugar beverages [*see box on opposite page*], and last year Washington, D.C., enacted a 6 percent tax on sugary drinks. New York City has also offered vouchers for buying produce at farmers' markets to low-income families and incentives to stores to offer healthier fare.

Some experts are trying to push the government to rewrite zoning and building codes to ensure that neighborhoods and buildings become friendlier to walkers, bikers and stair climbers. A 2009 study by researchers at Louisiana State University Medical School found that a mere 2.8 percent increase in a person's stair usage alone would keep off almost a pound a year. "The correlation between activity levels and healthy weight is one of the best-established ones in all of obesity research," says William M. Hartman, a psychologist and director of the behavioral program of the highly regarded Weight Management Program of the California Pacific Medical Center in San Francisco.

Increasing access to behavior therapy would help, too. Many overweight people might only need online behavioral monitoring, support and progress-sharing tools, which have proved moderately effective in studies. Others may need much more intensive, more personal interventions of the kind Cameron is developing. Given that obesity especially plagues the economically disadvantaged, fees for these programs may have to be heavily subsidized by the government and health care insurers. A weekly session with a behavioral therapist costing $50 would amount to $2,500 a year, or a bit more than a third of the $7,000 per year societal and medical costs of obesity—and the sessions might only be needed for a year or two to establish new, permanent eating and exercise habits, whereas the savings would continue on for a lifetime.

It is too soon to say whether the public will accept government efforts to push it toward healthier choices. In San Francisco, a community known to be especially friendly to public health initiatives, the plan to ban Happy Meals has provoked angry reactions, and Mayor Gavin Newsom vetoed it. Efforts by Let's Move to bring healthier food to school cafeterias have been intensely criticized by some as overly intrusive. Even if these efforts are eventually fully implemented nationwide, there is no way of being sure they will significantly reduce obesity. The current rate of obesity is far beyond any ever seen before on the planet, and thus a large-scale solution will necessarily be an experiment in mass behavior change. But the research suggests that such a grand experiment would be our best shot at fixing obesity and that there is reason to be hopeful it will succeed. Given that more and more scientists, public policy experts and government officials seem eager to get it off the ground, we may well have early findings within this decade. SA

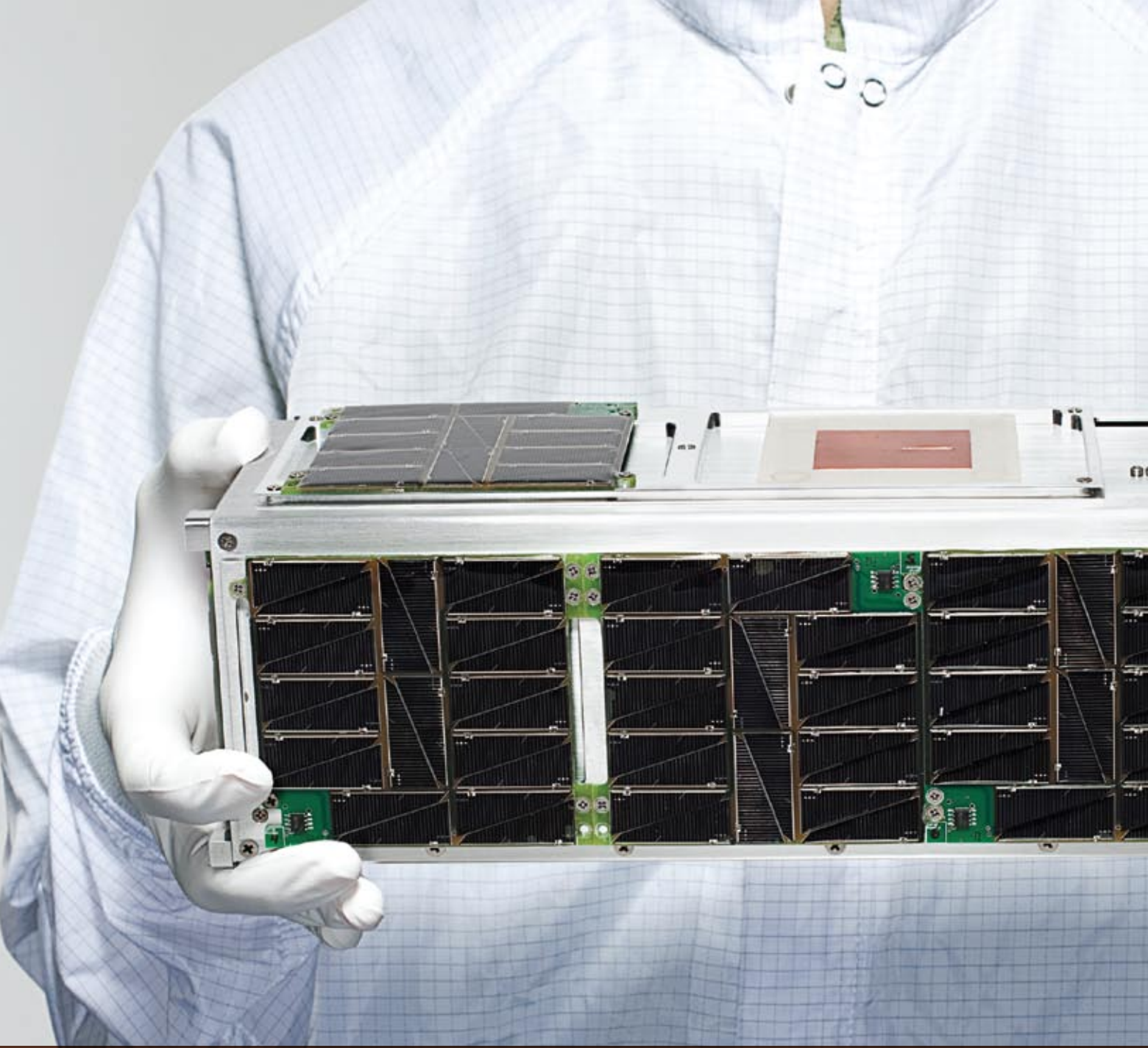
MORE TO EXPLORE

About Behaviorism. B. F. Skinner. Vintage, 1974. A classic in behavior modification.

You on a Diet: The Owner's Manual for Waist Management. Michael F. Roizen and Mehmet C. Oz. Free Press, 2006. Good layperson's guide to various aspects of weight management.

Determining the Effectiveness of Take Off Pounds Sensibly (TOPS), a Nationally Available Nonprofit Weight Loss Program. Nia S. Mitchell et al. in *Obesity.* Published online September 23, 2010. www.nature.com/oby/journal/vaop/ncurrent/full/oby2010202a.html

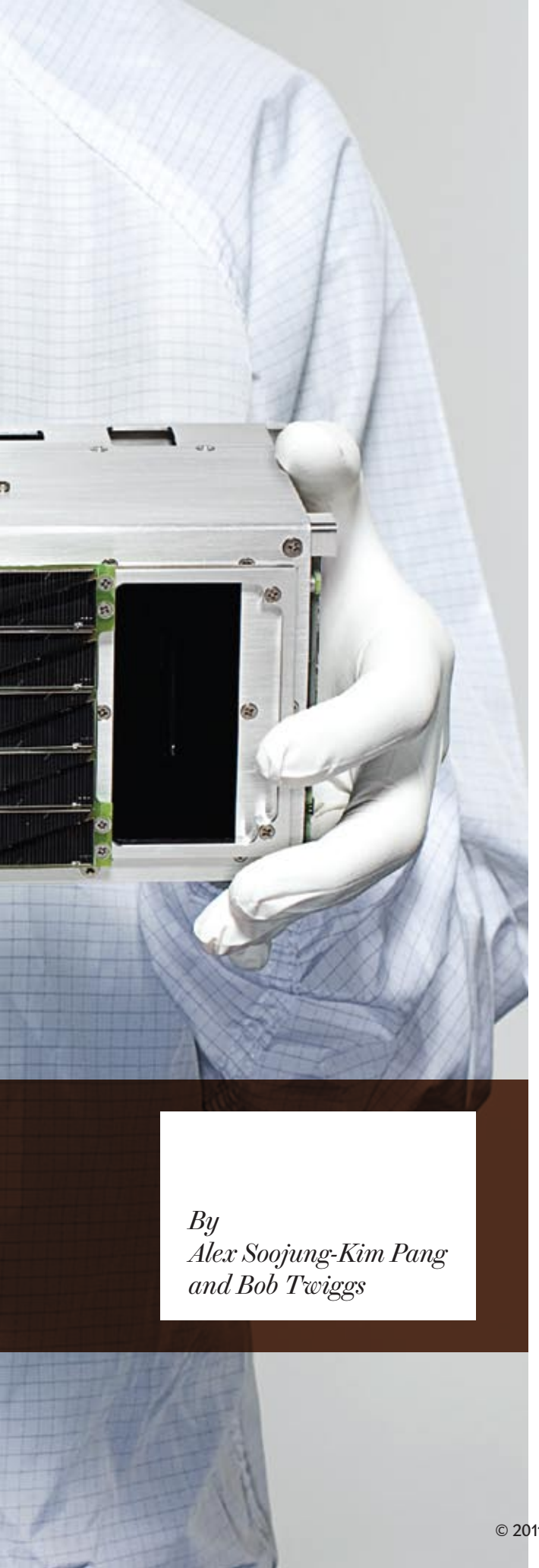
The entry portal to the range of NIH research on obesity: **obesityresearch.nih.gov**



SPACE

Citizen Satellites

Tiny, standardized spacecraft are making orbital experiments affordable to even the smallest research groups



By
Alex Soojung-Kim Pang and Bob Twiggs

Alex Soojung-Kim Pang holds a Ph.D. in history of science from the University of Pennsylvania and has written on the history of astronomy, scientific fieldwork, and the social impacts of emerging technologies. He is an associate fellow at University of Oxford's Saïd Business School and is currently a visiting fellow at Microsoft Research Cambridge.

Bob Twiggs was one of the originators of the CubeSat concept while at the department of aeronautics and astronautics at Stanford University. Since 2009 he has been a professor at Morehead State University in Kentucky. Twiggs has a B.S. in electrical engineering from the University of Idaho and an M.S. in electrical engineering from Stanford.

EVER SINCE SPUTNIK KICKED OFF THE AGE OF SPACE SATELlites more than fifty years ago, big institutions have dominated the skies. Almost all the many thousands of satellites that have taken their place in Earth orbit were the result of huge projects funded by governments and corporations. For decades each generation of satellites has been more complicated and expensive than its predecessor, taken longer to design, and required an infrastructure of expensive launch facilities, global monitoring stations, mission specialists and research centers.

In recent years, however, improvements in electronics, solar power and other technologies have made it possible to shrink satellites dramatically. A new type of satellite, called CubeSat, drastically simplifies and standardizes the design of small spacecraft and brings costs down to less than $100,000 to develop, launch and operate a single satellite—a tiny fraction of the typical mission budget of NASA or the European Space Agency.

A CubeSat is about the size of a Beanie Baby box—appropriate, given that until recently, most scientists regarded CubeSats as little more than toys. The idea behind CubeSats is to give satellite developers standard specifications for size and weight and then combine many satellites—each made by a different group of scientists, graduate students, engineers—into a single rocket payload, usually piggybacking on other, more expensive missions that have a bit of room to share. The high expense of the rocket launch thus gets spread out over all the participants, keeping costs low. And the

IN BRIEF

A standardized technology for satellites is making space missions more affordable and accessible than they have ever been before.

These one-liter, one-kilogram "CubeSats" are often made of components that are shared among researchers. They can also can piggyback on other missions' rockets.

The satellites can take as little as one year to develop and can be linked into networks of space sensors. Most also fall to the surface in a relatively short time, which means they do not add to orbiting space junk.

Universities, companies, countries and even hobbyists can afford to do serious science missions in fields ranging from atmospheric physics to microgravity experiments.

Researchers at the University of California, Berkeley, used the standard CubeSat shape and size for their Ions, Neutrals, Electrons, Magnetic Fields project (*left*).

Photograph by Spencer Lowell

CubeSat design standards allow participants to share design features and know-how and buy components off the shelf.

Since the CubeSat concept was introduced, scientists from the U.S., Asia, Europe and Latin America have successfully launched at least two dozen CubeSats, which have performed everything from biomedical research in microgravity to studies of the upper atmosphere. CubeSats' low cost, rapid development times and global user community, combined with their value as teaching tools, have made them increasingly popular. University teams—often consisting largely of college and grad students—have sprouted around the world. CubeSats are also enabling small countries, start-up companies and even high school teams to develop their own space programs. Soon launch costs may come down to about $10,000—low enough for space amateurs to follow suit. We think that CubeSats could do for space what the Apple II did for computing 30 years ago: spark an economic and technological revolution by placing a well-known but formerly inaccessible technology in the hands of just about everyone.

LAUNCHING AN IDEA

SMALL SATELLITES, weighing a few kilograms, have been around since the beginning of the Space Age; Sputnik 1 itself weighed just over 80 kilograms. But as rockets became more powerful, satellites grew larger and more complex, to the point where a typical communications or research satellite weighs several tons.

Meanwhile "microsatellites"—spacecraft weighing between 10 and 100 kilograms—were pushed to the margins of space science but never disappeared completely. For example, atmospheric scientists sent them up to explore the thermosphere, the layer of the atmosphere that extends from about 80 kilometers to about 600 kilometers above Earth's surface, and scores of OSCAR (for Orbiting Satellite Carrying Amateur Radio) communications satellites have been helping ham radio enthusiasts connect since the early 1960s. But the potential of small satellites really began to grow in the 1980s, thanks to electronic miniaturization and the development of precision manufacturing techniques and microelectromechanical systems, such as the tiny accelerometers now common in devices from iPhones to air bags.

By the late 1990s it seemed possible to create useful satellites that weighed only a kilogram—a size that would radically reduce development and launch expenses and encourage developers to explore novel ways of designing missions. NASA also actively encouraged engineers to come up with cheaper approaches to space science.

It was then that one of us (Twiggs, then at Stanford University's Space and Systems Development Lab), together with Jordi Puig-Suari, a professor at California Polytechnic State University, San Luis Obispo, realized that to get the small-satellite concept to fly, some standardization would be crucial, as would following the example of the open-source movement, which cheaply creates world-class software. So in 2000 the two engineers published the CubeSat specifications. The 10-page document established some simple prescriptions: each unit must be a cube of 10 centimeters on its side (plus or minus a tenth of a millimeter) and thus have a volume of one liter. It also must not weigh more than one kilogram. CubeSats can also be rectangular, taking up the space of two or three boxes with a single physical unit; those are called 2U or 3U CubeSats.

A CubeSat consists of a metal frame that contains and protects the electronics, instruments, communications and energy systems within it. CubeSats also often have solar panels on several sides and an antenna protruding from one end; some may soon have rudimentary navigation systems, with tiny nozzles that can stabilize the craft's attitude and orient it in a desired direction.

Members of the growing CubeSat community build on one another's experiences, sharing success stories and new design tricks.

The modular design means that the satellites can be launched in standard frames that hold several at a time, like the candy in a Pez dispenser, and eject their payload once the rocket reaches orbit. In 2003 Puig-Suari released the design of such an orbital deployer, which made it possible to safely carry and launch CubeSats as "stowaways" on rockets launched by the U.S. and Russian space agencies. That same year a company called Pumpkin, based in San Francisco, delivered the first commercial CubeSat kit—which combines ready-to-use components such as an electronics motherboard, a metal frame, a battery and solar panels to enable scientists with little or no experience in space missions to hit the ground running.

The CubeSats' innards are as diverse as the teams that build them. Open one up, and you may see a mix of aerospace hardware and off-the-shelf technology; customized scientific instruments; hardware recycled from earlier space missions; radio equipment from local electronics shops; or computer hardware cannibalized from PCs or purchased on eBay.

From the beginning, members of the CubeSat community have built on one another's experience, success stories and design tricks; newcomers quickly learn that you share everything but the payload. When developers find something that works—one model of ham radio that works in space longer than another, for example—they share their findings with other CubeSat designers.

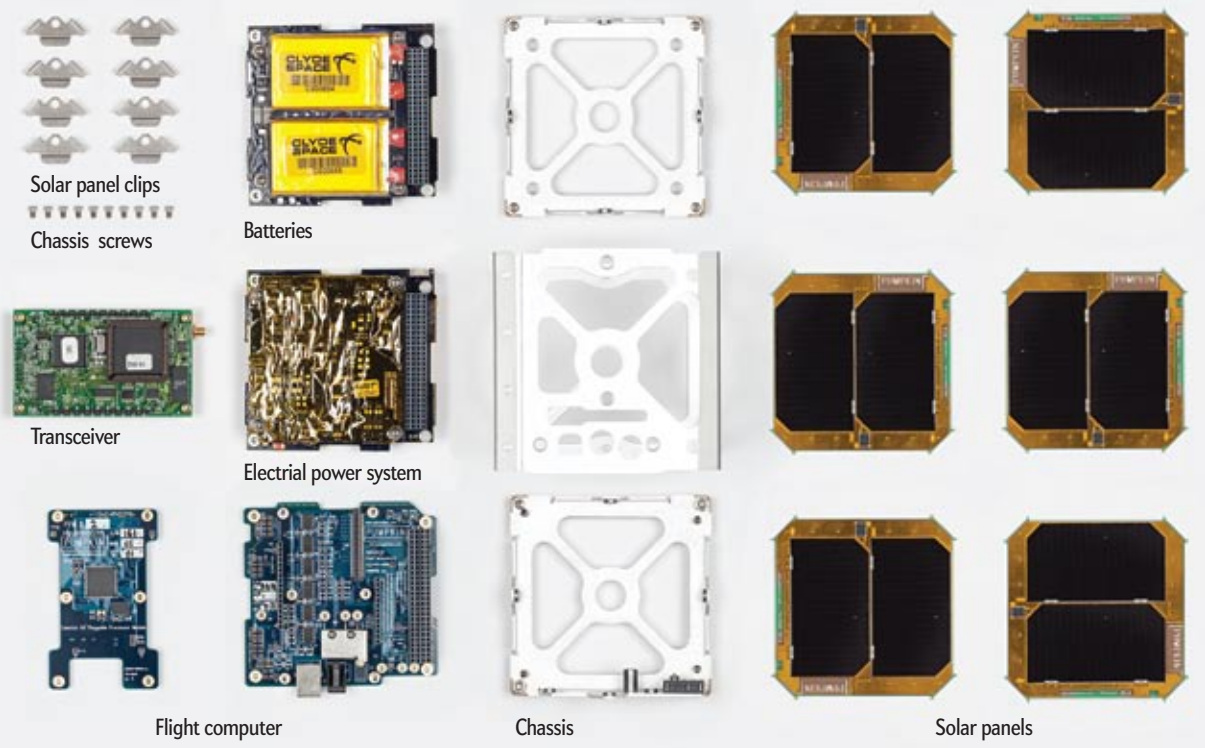
Soon we learned that students liked CubeSats, too, and could learn a lot from them. Students in traditional aerospace engineering programs work on theoretical projects or design small parts of large systems that go into space years after they graduate. A CubeSat, in contrast, is an object students can literally get their hands around. It can be built by a team working together in a single room. Students can create working satellites in a year or two, which makes them ideal thesis projects. They get hands-on responsibility on CubeSat projects: even undergrads can be project managers and mission specialists, and the possibility of seeing their work go into space is a great incentive to work hard. For educators, CubeSats are attractive because they present all the engineering issues of large satellites and thus offer students a way to acquire a deeper, more holistic feel for satellite design.

CUBIC SCIENCE

IN THE PAST FEW YEARS the range of scientists and institutions experimenting with CubeSats has greatly diversified. Aerospace engineers and astrophysicists have been joined by professors and students from other departments, and entrepreneurs have started companies offering launch services and support. Countries without much of a space program have been able to start one. Switzerland and Colombia have already launched their countries' first CubeSats, and several others—including Estonia—are working on their own. CubeSats even make it possible for individual U.S. states to start their own space programs. Most notably, Ken-

The Guts of a CubeSat

Ready-to-use assembly kits—such as one available from Pumpkin in San Francisco for $7,500—and other off-the-shelf parts give teams of scientists and engineers a chance to focus on the instruments for their experiments, rather than having to design entire spacecraft from scratch. The image below shows some parts from Pumpkin's kit (flight computer, solar panels and structural components) and some additional parts (Scotland's Clyde Space power system and batteries and a radio transceiver from Canada's Microhard Systems).



tucky has formed a consortium of academic and nonprofit institutions to build a CubeSat industry.

The state of the art has also moved from educationally oriented demonstration missions—"BeepSats," as early projects have been dubbed, because they often did little more than transmit radio signals to confirm that they were alive and prove that small satellites could communicate with stations on Earth—to more serious science. As NASA technologist Jason Crusan puts it, the CubeSat community can now point to a "critical mass of successful and significant missions that have shown results" and answer the objections of critics. CubeSats have evolved from toys into tools.

Those tools are being used in many areas, some controversial or highly experimental. QuakeSat, launched in 2003, was part of an effort to better predict earthquakes by detecting extremely low frequency (ELF) magnetic field changes. QuakeSat operated for a number of months and successfully sent back data to its ground station at Stanford, although most seismologists remain skeptical of a causal relation between ELFs and earthquakes or of the value of space-based ELF detection. Another example is LightSail-1, a 3U CubeSat designed by the Planetary Society to test the world's first solar-wind sail, a technology that could someday become a viable mode of propulsion around the solar system.

NASA, intelligence agencies and the military are also starting to experiment with CubeSats. This change of heart is remarkable given that a few years ago, mainstream space scientists believed that CubeSats would never be powerful or sophisticated enough for real science or surveillance, could not be maneuvered or controlled precisely, and would add space junk in valuable low Earth orbits. Even as microelectronics, sensors, batteries and other systems components improved, organizations accustomed to spending hundreds of millions of dollars and thousands of man-years to create satellites the size of automobiles still could not imagine that a quickly made satellite the size of a shoebox could be worth any attention.

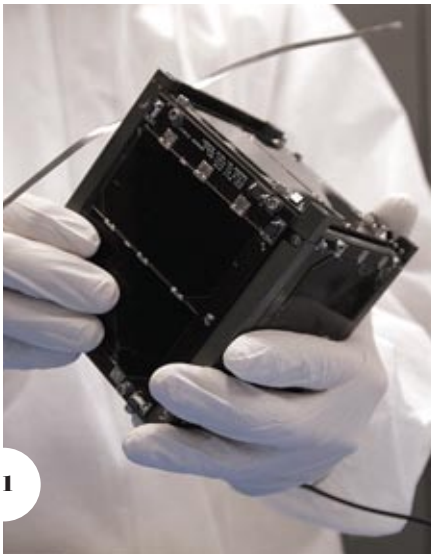
The National Reconnaissance Office's Colony 1 program, for example, is using CubeSats to test-fly new technologies before they are installed on larger craft. Other scientists have CubeSats performing more conventional pharmaceutical research. The Small Spacecraft Office, based at the NASA Ames Research Center in California's Silicon Valley, launched two CubeSats in 2006 and 2007, respectively, to test the feasibility of using familiar "lab on a chip" tools in low Earth orbit and see whether it would be possible for biologists to cheaply conduct experiments in microgravity. Three years later the group tested the effectiveness of an-

Photograph by Spencer Lowell

Cottage Industry of Space Science

1. Good attitude. Faculty and students at Cal Poly test a magnetic system for adjusting a CubeSat's flight attitude, in preparation for CP6, a CubeSat mission launched successfully in 2009.

2. New country. Switzerland launched its first satellite, SwissCube, in 2009. Built by a team that included around 200 students, the CubeSat observed the glow caused by cosmic rays in the upper atmosphere.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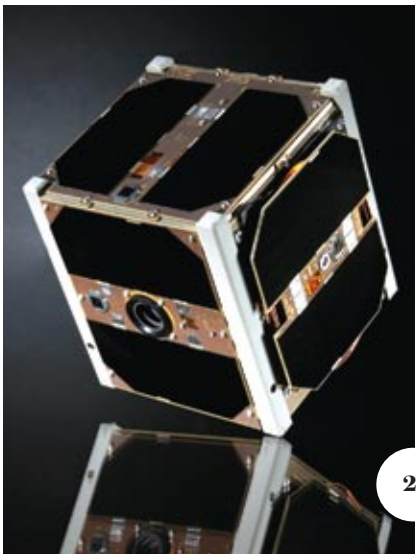
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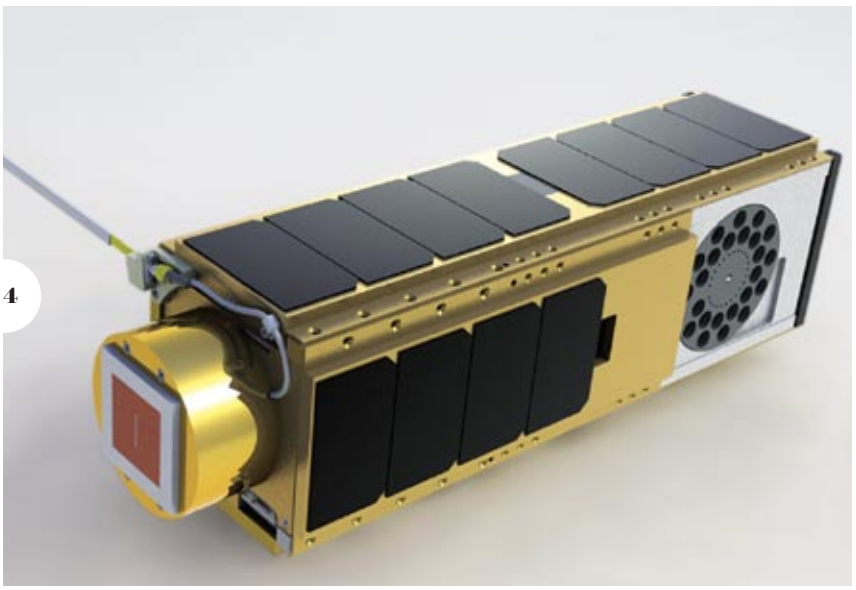
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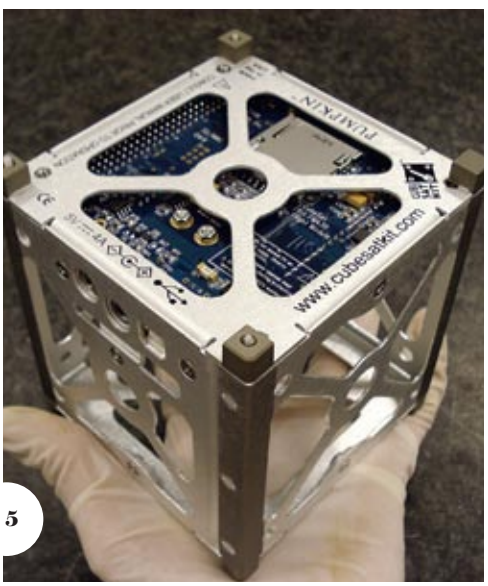

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3. Space weather. The Radio Aurora Explorer, launched last November, will study how solar wind affects Earth's ionosphere. The University of Michigan and SRI International built the satellite.

4. Life. NASA's Organism/Organic Exposure to Orbital Stresses CubeSat, launched last November, will demonstrate the ability to do low-cost biology experiments.

5. Ham radio. Students at the University of Liège in Belgium are building the Orbital Utility for Telecommunication Innovation for digital radio communications.

COURTESY OF CALIFORNIA POLYTECHNIC STATE UNIVERSITY (1); COURTESY OF EPFL (2); COURTESY OF SRI INTERNATIONAL (3); COURTESY OF NASA/AMES (4); COURTESY OF UNIVERSITY OF LIÈGE, BELGIUM (5)

tibacterial drugs in microgravity—the first step in designing a pharmacopeia for lengthy manned missions. And in July 2010 Houston-based company NanoRacks installed a CubeSat holder on the International Space Station and now leases space to pharmaceutical companies and other science-based industries interested in conducting research in space—as well as to educational institutions, including one high school.

Some CubeSats are devoted to weather and climate. CloudSat, designed by scientists at Colorado State University, will study vertical cloud structure and formation over a period of days, something meteorologists flying in aircraft have not been able to do. A mission supported by the National Science Foundation called Firefly will deploy a gamma-ray detector and photometer to measure terrestrial gamma-ray flashes, which shoot from Earth's atmosphere up into space, usually during lightning storms.

Both CloudSat and Firefly will observe phenomena in the troposphere, the 16-kilometer-deep atmospheric layer where humans live. Another class of CubeSats will study the thermosphere. The thermosphere is buffeted by solar wind, coronal discharges and sunspots, and its upper boundary rises and falls depending on solar activity. These changes can interfere with the performance of low-orbit satellites: the American space station Skylab crashed in 1979, when an unexpected rise in the thermosphere increased drag on the station and pulled it to Earth. Given that the International Space Station, GPS, and radio and television satellites orbit in the thermosphere, understanding this layer is as important for global communications and science as understanding the oceans is for global trade. Larger satellites at higher orbits cannot observe the thermosphere directly; instead they see it wedged between the exosphere (the thin layer between Earth and space) and the stratosphere (the layer directly below the thermosphere), while instruments on sounding rockets take direct measurements, but only in the small column of the rockets' trajectory and for a few minutes.

SEE HOW CUBESATS ARE MADE
ScientificAmerican.com/feb2011/cubesats

The first thermosphere CubeSat to reach space was Switzerland's SwissCube, launched in late 2009. SwissCube measures and maps airglow, the very faint light emitted by chemical and physical reactions in the upper atmosphere, to help scientists better understand its causes and more effectively filter it out when studying other atmospheric or terrestrial phenomena.

A NEW ECONOMY OF SPACE

PERHAPS THE MOST DISRUPTIVE innovation brought about by CubeSats has been their introduction of a new business model into the economics of space. CubeSats from different groups are usually bundled together and launched as secondary payloads. This means CubeSats launch when it is convenient for the owners of the primary payload, but flying coach saves money and distributes launch costs among many participants. Further, as Kris W. Kimel, president and founder of Kentucky Science and Technology Corporation, explains, the low cost of CubeSats "lets you fail, and it lets you innovate. That's a key to entrepreneurship." Low costs create a higher tolerance for failure throughout the design and deployment process: for CubeSats, blowing up on the launchpad or refusing to deploy once in space hurts less. (And stuff does happen: 14 CubeSats were lost in a 2006 rocket failure, and another nine made no or limited contact with ground stations.) "If you lose one, you don't like it," Kimel says. "But it's not like you've lost $5 million." Conventional satellites, in contrast, are "too big to fail," says Andrew Kalman, Pumpkin's president and chief technology architect.

Some missions take this attitude one step further: they deliberately put their CubeSats in self-destructing orbits to generate interesting data. "CubeSats can go places where they won't live very long," Puig-Suari notes. "I can make a disposable satellite that I can usefully put in hazardous locations. Not only can you tolerate failure, you can design for it and take advantage of it."

Two examples of this approach are missions that Twiggs helped to design. The first is a collaboration of European, Asian and American teams called QB50. The consortium will launch 50 double-cube CubeSats in the upper edge of the thermosphere. Over several months, as atmospheric friction slows the satellites, their orbits will decay, and they will gather information about the chemical composition, density and temperature of the thermosphere at progressively lower altitudes, until they finally fall to Earth.

The second example is a mission called the Polar Orbiting Passive Atmospheric Calibration Sphere. It will launch three 3U CubeSats to measure the heating of Earth's atmosphere by solar flares. As the satellites fly through the polar atmosphere, scientists will watch how their orbits decay and expect to learn how to better predict the relation between the thermosphere and solar activity.

CubeSats' small size and their relatively weak communications systems still impose harsh limits on an individual spacecraft's ability to gather much interesting data. This is one reason most missions have been double or triple cubes, and why scientists are now experimenting with deploying CubeSat networks in which the satellites are able to coordinate and work together, much in the same way birds flock and migrate. Developers are working on intersatellite communications, systems to permit formation flying, and even kilometers-long tethers to keep satellites joined together. Finally, the Defense Advanced Research Projects Agency is sponsoring a $75-million research project on CubeSat networks to understand under what circumstances CubeSats can replace traditional satellites. Stable constellations of CubeSats might even provide an alternative to large instruments: Gil Moore, an emeritus professor at Utah State University, envisions being able to "put up large, sparse arrays that will do what the Hubble and Webb space telescopes do."

To further extend CubeSats' capabilities, Paulo Lozano of the Massachusetts Institute of Technology has developed a tiny electronic propulsion system that would enable CubeSats to be steered. Others are working on printing CubeSat components, which would reduce costs.

Ultimately, Kalman says, scientists will be able to treat CubeSats like personal computers: they will be "a foundation on which people can build their own apps." The idea that CubeSats could be the PCs of space science—cheap, flexible, commoditized and standardized—suggests a final and potentially even more revolutionary role: enabling an amateur presence in space. This may come sooner rather than later: space start-up Interorbital Systems in Mojave, Calif., plans to offer CubeSat kits and low-Earth-orbit launch for less than $10,000. "Amateurs will have a chance to participate," Puig-Suari says. "People are going to start building their own mini Hubbles." SA

MORE TO EXPLORE

CubeSat Design Specification Revision 12. California Polytechnic State University, 2009.
The official Web site of the CubeSat project: www.cubesat.org

IN BRIEF

Meat consumption is rising worldwide, but production involves vast amounts of energy, water and emissions. At the same time, wild fisheries are declining. Aquaculture could become the most sustainable source of protein for humans.

Fish farming already accounts for half of global seafood production. Most of it is done along coastlines, which creates substantial water pollution.

Large, offshore pens that are anchored to the seafloor are often cleaner. Those farms, other new forms of aquaculture, and practices that clean up coastal operations could expand aquaculture significantly.

Questions remain about how sustainable and cost-effective the approaches can be.

Fish raised in offshore pens, such as these yellowtail at Kona Blue Water Farms near Hawaii, could become a more sustainable source of protein for humans than wild fish or beef.

SUSTAINABILITY

The Blue Food Revolution

New fish farms out at sea, and cleaner operations along the shore, could provide the world with a rich supply of much needed protein

By Sarah Simpson

Sarah Simpson is a freelance writer and contributing editor for *Scientific American*. She lives in Riverside, Calif.

NEIL SIMS TENDS HIS ROWDY STOCK LIKE ANY DEvoted farmer. But rather than saddling a horse like the Australian sheep drovers he grew up with, Sims dons a snorkel and mask to wrangle his herd: 480,000 silver fish corralled half a mile off the Kona coast of Hawaii's Big Island.

Tucked discretely below the waves, Sims's farm is one of 20 operations worldwide that are trying to take advantage of the earth's last great agricultural frontier: the ocean. Their offshore locations offer a distinct advantage over the thousands of conventional fish farms—flotillas of pens that hug the coastline. Too often old-style coastal farms, scorned as eyesores and ocean polluters, exude enough fish excrement and food scraps to cloud the calm, shallow waters, triggering harmful algal blooms or snuffing out sea life underneath the pens. At offshore sites such as Kona Blue Water Farms, pollution is not an issue, Sims explains. The seven submerged paddocks, each one as big as a high school gymnasium, are anchored within rapid currents that sweep away the waste, which is quickly diluted to harmless levels in the open waters.

Rather than taking Sims's word for it, I put swim fins on my feet and a snorkel around my neck, high-step to the edge of his small service boat, and take the plunge. From the water, the double-cone-shape cage is aglow like a colossal Chinese lantern, with shimmering streams of sunlight and glinting forms of darting fish. To the touch, the material that stretches taut around the outside of the cage's frame feels more like a fence than a net. The solid, Kevlar-esque material would repel hungry sharks as effectively as it contains teeming masses of *Seriola rivoliana,* a local species of yellowtail that Kona Blue has domesticated as an alternative to wild tuna.

Why yellowtail? Many wild tuna fisheries are collapsing, and sushi-grade yellowtail fetches a high price. Sims and fellow marine biologist Dale Sarver founded Kona Blue in 2001 to raise popular fish sustainably. But the company's methods could just as well be applied to run-of-the-mill fish—and we may need them. The global population of 6.9 billion people is estimated to rise to 9.3 billion by 2050, and people with higher living standards also tend to eat more meat and seafood. Yet the global catch from wild fisheries has been stagnant or declining for a decade. Raising cows, pigs, chickens and other animals consumes vast amounts of land, freshwater, fossil fuels that pollute the air and fertilizers that run off and choke rivers and oceans.

Where will all the needed protein for people come from? The answer could well be new offshore farms, if they can function efficiently, and coastal farms, if they can be cleaned up.

CLEANER IS BETTER

TO SOME SCIENTISTS, feeding the world calls for transferring the production of our animal protein to the seas. If a blue food revolution is to fill such an exalted plate at the dinner table, however, it must operate in environmentally sound ways—and make its benefits better known both to a jaded public and to policy makers with the power to help or retard its spread.

In the past, condemnation might have been apt. When modern coastal fish farming began about 30 years ago, virtually no one was doing things right, either for the environment or for the industry's long-term sustainability. Fish sewage was just one of the issues. Shrimp farmers in Southeast Asia and Mexico clear-cut coastal mangrove forests to make ponds to grow their shrimp. In the salmon farms of Europe and the Americas, animals were often too densely packed, helping disease and parasites sweep through the populations. Fish that escaped farms sometimes spread their diseases to native species. Making matters worse, the aquaculture industry represented (and

MASA USHIODA *CoolWaterPhoto.com (preceding pages);*
GRAPHIC SOURCES: UNITED NATIONS FOOD AND AGRICULTURE ORGANIZATION; NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

FEEDING THE WORLD

Protein Supply: Land or Sea?

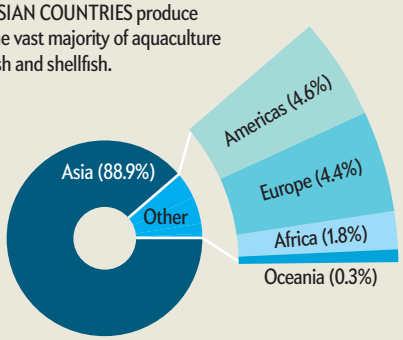
The World Needs More Protein

WORLD POPULATION will increase from 6.9 billion to 9.3 billion by 2050.

CROP AND GRAZING areas, at today's yields, would have to rise by 50% to 70% to meet 2050 food needs; such land may not exist.

Who Is Poised to Provide It?

ASIAN COUNTRIES produce the vast majority of aquaculture fish and shellfish.



AQUACULTURE produces 47% of the global seafood people consume. It could sustainably provide 62% of the world's total protein by 2050 if it continues to grow at its current annual rate of 7.4% and agriculture continues its 2.0% growth rate.

Graphics by Jen Christiansen

still does) a net drain on fish mass; wild forage fish—small, cheap species that humans do not prefer but that bigger, wild fish eat—are captured in large quantities and ground into feed for the bigger, tastier, more expensive farmed fish folks favor.

Clearly, such ills were not good for business, and the industry has devised innovative solutions. Kona Blue's strategy of situating the farm within rapid offshore currents is one example. Other farmers are beginning to raise seaweed and filter-feeding animals such as mollusks near the fish pens to gobble up waste. Throughout the industry, including freshwater pens, improvements in animal husbandry and feed formulations are reducing disease and helping fish grow faster, with less forage fish in their diets. It may still be a long time before environmental groups remove farmed fish from "don't buy" lists, however.

Some cutting-edge thinkers are experimenting with an even bolder move. Nations exercise sole rights to manage waters out to 200 nautical miles from their shores—a vast frontier untapped for domesticated food production. Around the U.S., that frontier measures 3.4 million square nautical miles. Submerged fish pens, steered by large propellers, could ride in stable ocean currents, returning months later to their starting points or a distant destination to deliver fresh fish for market.

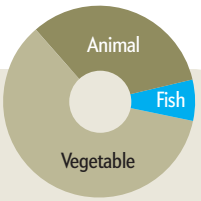
Ocean engineer Clifford Goudey tested the world's first self-propelled, submersible fish pen off the coast of Puerto Rico in late 2008. A geodesic sphere 62 feet in diameter, the cage proved surprisingly maneuverable when outfitted with a pair of eight-foot propellers, says Goudey, former director of M.I.T. Sea Grant's Offshore Aquaculture Engineering Center. Goudey imagines launching dozens of mobile farms in a steady progression within a predictable current that traverses the Caribbean Sea every nine months.

FEEDING FRENZY

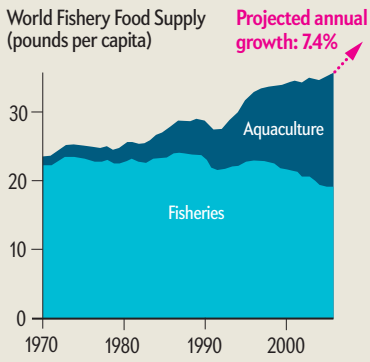
THE ASPECT OF MARINE (SALTWATER) AQUACULTURE that has been hardest to fix is the need to use small, wild fish as food for the large, farmed varieties. (The small fish are not farmed, because a mature industry already exists that catches and grinds them into fish meal and oil.) The feed issue comes into pungent focus for me when Sims and I climb aboard an old U.S. Navy transport ship cleverly transformed into a feeding barge. The sea swell pitches me sideways as I make my way to the bow, calling to mind a bumpy pickup truck ride I took long ago, across a semifrozen Missouri pasture to deliver hay to my cousin's Herefords. The memory of sweet-smelling dried grass vanishes when I grab a handful of oily brown feed from a 2,000-pound sack propped open on the deck. The pellets look like kibble for a small terrier but reek of an empty anchovy tin.

The odor is no surprise; 30 percent of Kona Blue's feed is ground up Peruvian anchovy. Yellowtail could survive on a vegetarian diet, but they wouldn't taste as good, Sims explains. Nor would their flesh include all the fatty acids and amino acids that make them healthy to eat. Those ingredients come from fish meal and fish oil, and that is the issue. "We are often pilloried because we're killing fish to grow fish," Sims says. Salmon farming, done in coastal pens, draws the same ire.

Detractors worry that rising demand from fish farms will wipe out wild anchovies, sardines and other forage fish. Before modern fish farming began, most fish meal was fed to pigs and

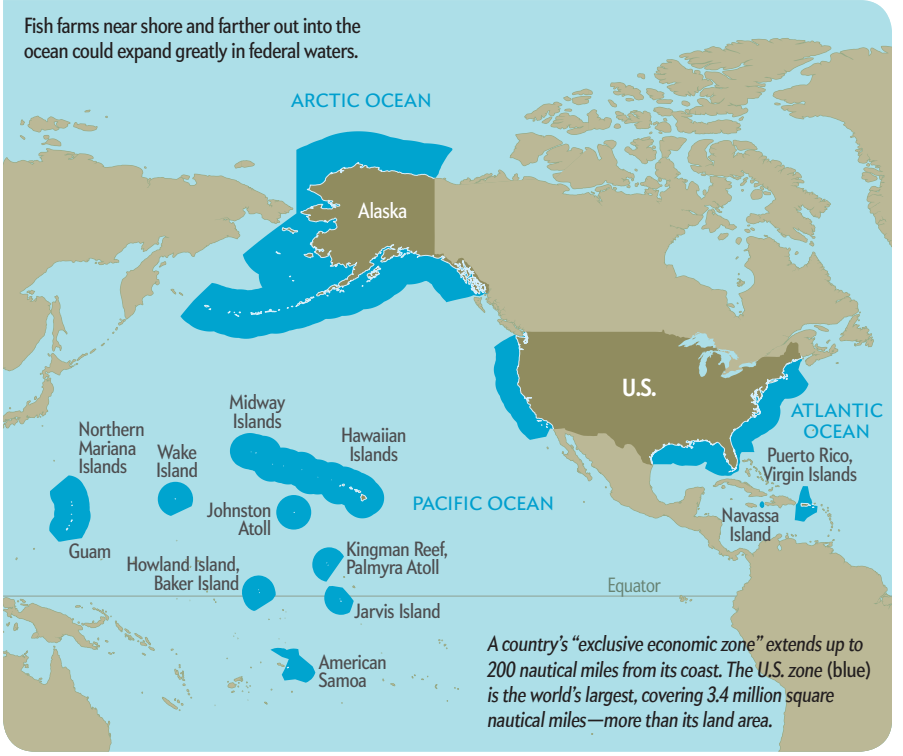


FISH supply only 7% of the world's protein.



The U.S. Has Vast Potential

Fish farms near shore and farther out into the ocean could expand greatly in federal waters.



A country's "exclusive economic zone" extends up to 200 nautical miles from its coast. The U.S. zone (blue) *is the world's largest, covering 3.4 million square nautical miles—more than its land area.*

Map by XNR Productions

chickens, but today aquaculture consumes 68 percent of the fish meal. Consumption has lessened under advanced feed formulas, however. When Kona Blue started raising yellowtail in 2005, its feed pellets were 80 percent anchovy. By early 2008 the company had reduced the share to 30 percent—without sacrificing taste or health benefit, Sims says—by increasing the concentration of soybean meal and adding chicken oil, a by-product of poultry processing. The compound feed pellets are a big improvement over the egregious practice of dumping whole sardines into the fish cages. Unfortunately, this wasteful habit remains the norm among less responsible farmers.

A goal for the more enlightened proprietors is a break-even ratio, in which the amount of fish in feed equals the weight of fish produced for market. Farmers of freshwater tilapia and catfish have attained this magic ratio, but marine farmers have not. Because 70 percent of Kona Blue's feed is agricultural protein and oil, it now needs only 1.6 to 2.0 pounds of anchovies to produce one pound of yellowtail. The average for the farmed salmon industry is around 3.0. To achieve no net loss of marine protein, the industry would have to reduce that ratio. Still, farmed fish take a far smaller bite than their wild equivalents do: over its lifetime, a wild tuna may consume as much as 100 pounds of food per pound of its own weight, all of it fish.

The pressure to reduce sardine and anchovy catches will increase as the number of fish farms grows. Aquaculture is the fastest-growing food production sector in the world, expanding at 7.5 percent a year since 1994. At that pace, fish meal and fish oil resources could be exhausted by 2040. An overarching goal, therefore, is to eliminate wild fish products from feed altogether, within a decade or so, asserts marine ecologist Carlos M. Duarte, who directs the International Laboratory for Global Change at the Spanish Council for Scientific Research in Majorca.

One breakthrough that could help is coaxing the coveted omega-3 fatty acid DHA out of microscopic algae, which could replace some of the forage fish content in feed. Advanced BioNutrition in Columbia, Md., is testing feed that contains the same algae-derived DHA that enhances infant formula, milk and juice now sold in stores. Recently researchers at Australia's Commonwealth Scientific and Industrial Research Organization coaxed DHA out of land plants for the first time. Duarte suggests that fierce competition for agricultural land and freshwater means that fish farmers should eventually eliminate soy, chicken oil and other terrestrial products as well, instead feeding their flocks on zooplankton and seaweed, which is easy to grow. (Seaweed already accounts for nearly one quarter of all marine aquaculture value.)

Despite improvements in marine fish farming, prominent environmentalists and academics still shoot it down. Marine ecologist Jeremy Jackson of the Scripps Institution of Oceanography says he is "violently opposed" to aquaculture of predatory fish and shrimp—basically, any fish people like to eat sashimi-style. He calls the practice "environmentally catastrophic" in the pressure it puts on wild fish supplies and insists it should be "illegal."

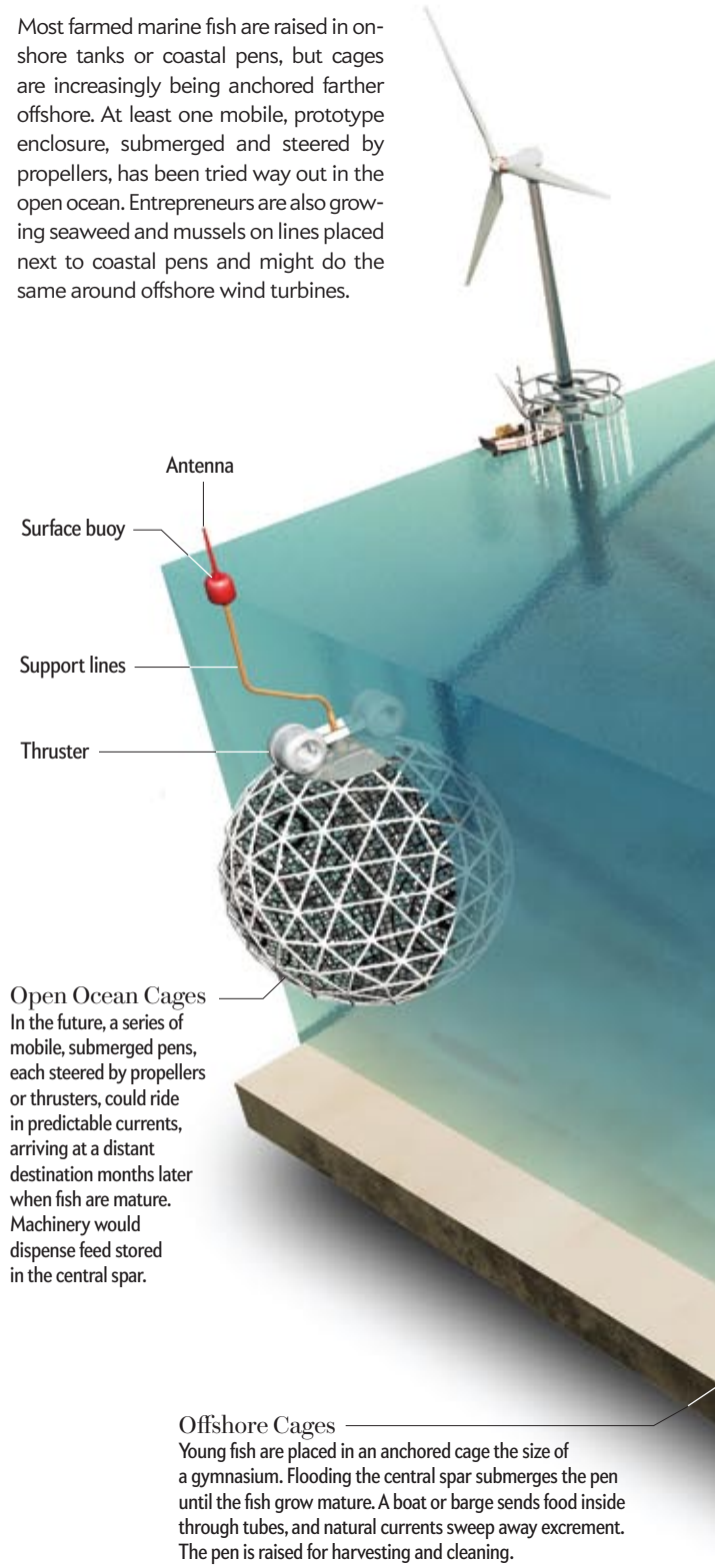
SMARTER THAN BEEF

JACKSON'S POINT, echoed by other critics, is that the risk of collapsing forage fisheries, which are already overexploited, is too great to justify serving up a luxury food most of the world will never taste. Far better would be to eat the herbivorous sardines and anchovies directly instead of farmed, top-end predators.

HOW IT WORKS

Five Ways to Raise Seafood

Most farmed marine fish are raised in onshore tanks or coastal pens, but cages are increasingly being anchored farther offshore. At least one mobile, prototype enclosure, submerged and steered by propellers, has been tried way out in the open ocean. Entrepreneurs are also growing seaweed and mussels on lines placed next to coastal pens and might do the same around offshore wind turbines.



Open Ocean Cages
In the future, a series of mobile, submerged pens, each steered by propellers or thrusters, could ride in predictable currents, arriving at a distant destination months later when fish are mature. Machinery would dispense feed stored in the central spar.

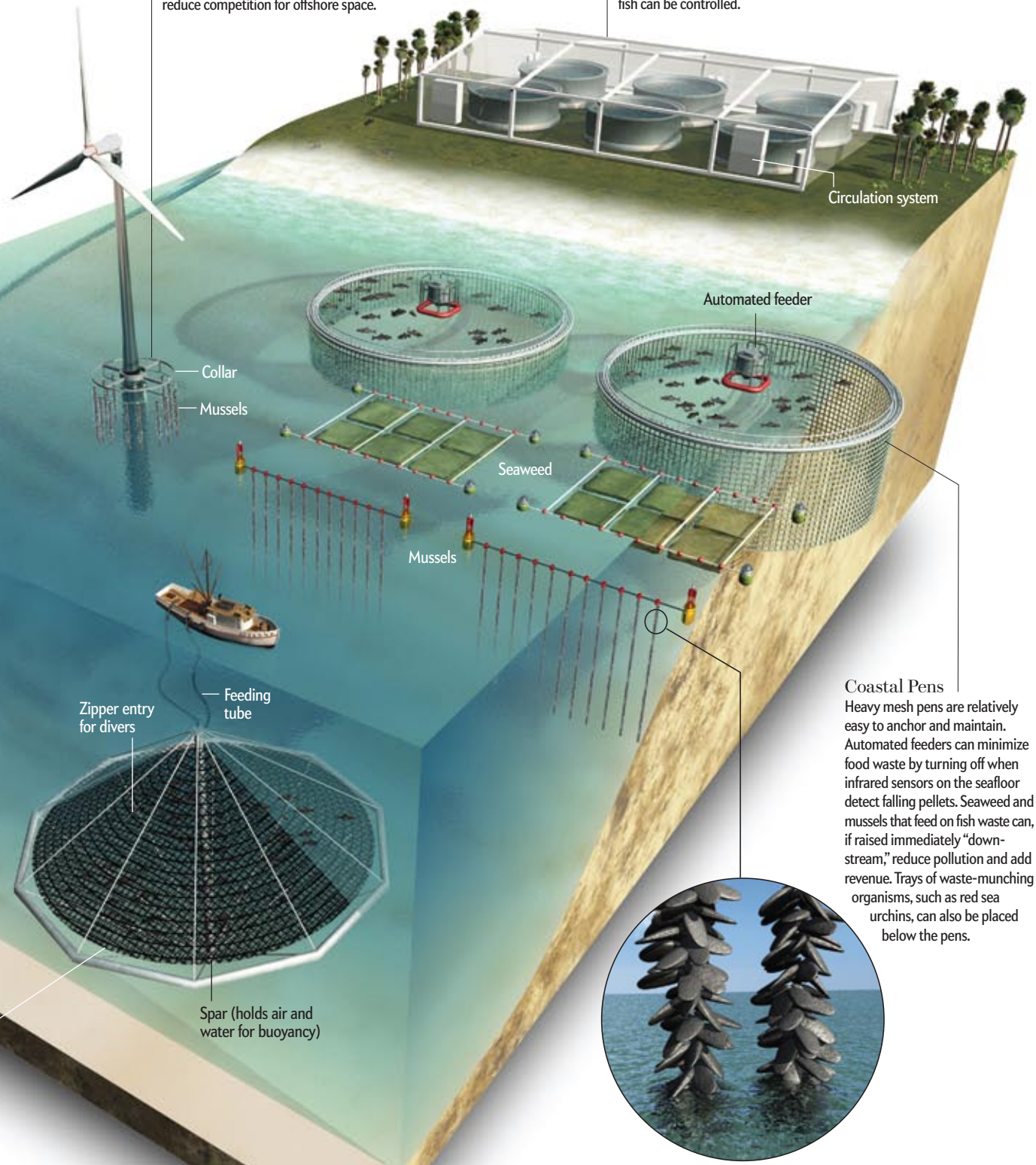
Offshore Cages
Young fish are placed in an anchored cage the size of a gymnasium. Flooding the central spar submerges the pen until the fish grow mature. A boat or barge sends food inside through tubes, and natural currents sweep away excrement. The pen is raised for harvesting and cleaning.

Turbine Collars

Mussels and seaweed readily cling to synthetic lines and grow naturally. The lines could be strung around or between turbines in offshore wind farms to enhance investment and to help reduce competition for offshore space.

Onshore Tanks

All marine fish are hatched in tanks on land. Many are moved to pens at sea when old enough (fingerlings), but some innovators are also raising fish to harvestable size in onshore tanks, where pollutants, disease and escaped fish can be controlled.



Coastal Pens

Heavy mesh pens are relatively easy to anchor and maintain. Automated feeders can minimize food waste by turning off when infrared sensors on the seafloor detect falling pellets. Seaweed and mussels that feed on fish waste can, if raised immediately "downstream," reduce pollution and add revenue. Trays of waste-munching organisms, such as red sea urchins, can also be placed below the pens.

Illustration by Don Foley

Farmed yellowtail grow more efficiently than wild fish, which expend much energy hunting and evading predators.

Sims agrees that we should *fish* lower on the food web but says that does not mean we need to *eat* lower. "Let's get real. I eat anchovies on my pizza, but I can't get anyone else in my family to do it," he says. "If you can get a pound of farmed sushi for every pound of anchovy, why not give people the thing they want to eat?"

Certain people scoff at fish consumption—whether wild-caught or farm-raised—on the premise that the planet and its human inhabitants would be healthier if people ate more plants. But society is not rushing to become vegetarian. More people are eating more meat, particularly as populations in the developing world become wealthier, more urban and more Western. The World Health Organization predicts a 25 percent increase in per capita meat consumption by 2050. Even if consumption held steady, crop and grazing areas would have to increase by 50 to 70 percent, at current yields, to produce the food required in 2050.

That reality begs for a comparison rarely made: fish farming versus terrestrial farming. Done right, fish farming could provide much needed protein for the world while minimizing the expansion of land-based farming and the attendant environmental costs.

Land-based farmers have already transformed 40 percent of the earth's terrestrial surface. And after 10,000 years to work out the kinks, major problems still abound. Cattle eat tremendous amounts of heavily fertilized crops, and pig and chicken farms are notorious polluters. The dead zones underneath coastal fish farms pale in comparison to the huge dead zones that fertilizer run-off triggers in the Gulf of Mexico, Black Sea and elsewhere and to the harmful algal blooms that pig farm effluent has caused in Chesapeake Bay.

A growing number of scientists are beginning to compare the environmental impacts of all the various protein production systems, so that society can "focus its energies on efficiently solving the most demanding problems," writes Kenneth M. Brooks, an independent aquatic environmental consultant in Port Townsend, Wash. Brooks estimates that raising Angus beef requires 4,400 times more high-quality pasture land than seafloor needed for the equivalent weight of farmed Atlantic salmon filets. What is more, the ecosystem below a salmon farm can recover in less than a decade, instead of the centuries it would take for a cattle pasture to revert to mature forest.

An even more compelling reason to raise protein in the sea may be to reduce humanity's drain on freshwater. As Duarte points out, animal meat products represent only 3.5 percent of food production but consume 45 percent of the water used in agriculture. By shifting most protein production to the ocean, he says, "land agriculture could grow considerably without exceeding current levels of water use."

Of course, collecting and transporting soybean meal and chicken oil and feeding fish flocks all consume energy and create emissions, too. Fuel consumption and emissions are greater for farms that are farther from shore, but both types of farming rate better than most fishing fleets. The only way offshore farmers can be profitable right now is to raise high-priced fish, but costs can come down: a few experimental farms are already raising cost-competitive mussels in the ocean.

ENVIRONMENTAL DISTINCTIONS

IF PROVIDING MORE FISH TO CONSUMERS is an answer to meeting global demands for protein, why not just catch more fish directly? Many wild fisheries are maxed out, right at a time when global population, as well as per capita demand for fish, is boom-

MASA USHIODA *CoolWaterPhoto.com*

ing. North Americans, for example, are heeding health experts' advice to eat fish to help reduce the risk of heart attacks and improve brain function.

What is more, fishing fleets consume vast amounts of fuel and emit volumes of greenhouse gases and pollutants. Widely used, indiscriminate fishing methods, such as trawling and dredging, kill millions of animals; studies indicate that at least half the sea life fishers haul in this way is discarded as too small, overquota or the wrong species. All too often this so-called by-catch is dead by the time it is tossed overboard. Aquaculture eliminates this waste altogether: "Farmers only harvest the fish in their pens," Sims notes.

Goudey points out another often overlooked reality: you can grow fish more efficiently than you can catch them. Farmed fish convert food into flesh much more effectively than their wild brethren, which expend enormous amounts of energy as they hunt for food and evade predators, seek a mate and reproduce. Farmed fish have it easy by comparison, so most of their diet goes into growth.

Kona Blue's yellowtail and most farmed salmon are between one and three years old at harvest, one-third the age of the large, wild tuna targeted for sushi. The younger age also means farmed fish have less opportunity to accumulate mercury and other persistent pollutants that can make mature tuna and swordfish a potential health threat.

Indeed, fish farming already accounts for 47 percent of the seafood people consume worldwide, up from only 9 percent in 1980. Experts predict the share could rise to 62 percent of the total protein supply by 2050. "Clearly, aquaculture is big, and it is here to stay. People who are against it really aren't getting it," says Jose Villalon, aquaculture director at the World Wildlife Fund. Looking only at the ills of aquaculture is misleading if they are not compared with the ills of other forms of food production. Aquaculture affects the earth, and no number of improvements will eliminate all problems. But every food production system taxes the environment, and wild fish, beef, pork and poultry producers impose some of the greatest burdens.

SEE A SLIDE SHOW OF FISH FARMS
ScientificAmerican.com/feb2011/simpson

To encourage good practices and help distinguish clean fish farms from the worst offenders, the World Wildlife Fund has cofounded the Aquaculture Stewardship Council to set global standards for responsible practices and to use independent auditors to certify compliant farms. The council's first set of standards is expected early this year. The council believes certification could have the greatest effect by motivating the world's 100 to 200 big seafood retailers to buy fish from certified farms, rather than trying to crack down directly on thousands of producers.

The Ocean Conservancy's aquaculture director George Leonard agrees that this kind of farm-to-plate certification program is an important way to encourage fish farmers to pursue better sustainability practices. As in any global industry, he says, cheap, unscrupulous providers will always exist. Setting a regulatory "floor" could require U.S. farmers to behave responsibly "without making it impossible for them to compete."

That point is key. Only five of the world's 20 offshore installations are in U.S. waters. Goudey thinks more aquaculture entrepreneurs would dive in if the U.S. put a licensing system into place for federal waters, from three nautical miles offshore to the 200-mile boundary. "No investor is going to back a U.S. operation when there are no statutes granting rights of tenancy to an operation," Goudey asserts. All U.S. farms exist inside the three-mile-wide strip of water that states control, and only a few states, such as Hawaii, allow them. California has yet to grant permits, despite government estimates that a sustainable offshore fish-farming industry in less than 1 percent of the state's waters could bring in up to $1 billion a year.

PROTEIN POLICY

TO GROW, AND DO SO SUSTAINABLY, the fish-farming industry will need appropriate policies and a fairer playing field. At the moment, robust government fuel subsidies keep trawling and dredging fleets alive, despite their well-known destruction of the seafloor and the terrible volume of dead by-catch. Farm subsidies help to keep beef, pork and poultry production profitable. And powerful farm lobbies continue to block attempts to curtail the flow of nitrogen-rich fertilizer down the Mississippi River. "Almost none of these more traditional ways of producing food have received the scrutiny that aquaculture has," Brooks says. The public has accepted domestication of the land but maintains that the ocean is a wild frontier to be left alone, even though this imbalance may not be the most sustainable plan for feeding the world.

Policy shifts at the federal and regional levels may soon open up U.S. federal waters. In January 2009 the Gulf of Mexico Fishery Management Council voted in favor of an unprecedented plan for permitting offshore aquaculture within its jurisdiction, pending approval from higher levels within the U.S. National Oceanic and Atmospheric Administration. NOAA will evaluate the plan only after it finalizes its new national aquaculture policy, which addresses all forms of the industry and will probably include guidance for the development of a consistent, nationwide framework for regulating commercial activities. "We don't want the blue revolution to repeat the mistakes of the green revolution," says NOAA director Jane Lubchenco. "It's too important to get it wrong, and there are so many ways to get it wrong."

Given relentlessly rising demand, society has to make hard choices about where greater protein production should occur. "One of my goals has been to get us to a position where, when people say food security, they don't just mean grains and livestock but also fisheries and aquaculture," Lubchenco says. Duarte suggests we take some pressure off the land and turn to the seas, where we have the opportunity to do aquaculture right, rather than looking back 40 years from now wishing we had done so.

As for Neil Sims's part of the blue food revolution, he is courting technology companies for upgrades. Tools such as robotic net cleaners, automated feeders and satellite-controlled video cameras to monitor fish health and cage damage would help Kona Blue's crew manage its offshore farms remotely. "Not just so we can grow more fish in the ocean," Sims says. "So we can grow more fish *better*." SA

MORE TO EXPLORE

The State of World Fisheries and Aquaculture 2008. FAO, 2009.

Will the Oceans Help Feed Humanity? Carlos M. Duarte et al. in *BioScience*, Vol. 59, No. 11, pages 967–976; December 2009.

Sustainability and Global Seafood. Martin D. Smith et al. in *Science*, Vol. 327, pages784–786; February 12, 2010.

Will Farmed Fish Feed the World? An analysis from the Worldwatch Institute. www.worldwatch.org/node/5883

Lera Boroditsky is an assistant professor of cognitive psychology at Stanford University and editor in chief of *Frontiers in Cultural Psychology*. Her lab conducts research around the world, focusing on mental representation and the effects of language on cognition.

COGNITIVE PSYCHOLOGY

How Language Shapes Thought

The languages we speak affect our perceptions of the world

By Lera Boroditsky

I AM STANDING NEXT TO A FIVE-YEAR OLD GIRL IN PORMPURAAW, A SMALL Aboriginal community on the western edge of Cape York in northern Australia. When I ask her to point north, she points precisely and without hesitation. My compass says she is right. Later, back in a lecture hall at Stanford University, I make the same request of an audience of distinguished scholars—winners of science medals and genius prizes. Some of them have come to this very room to hear lectures for more than 40 years. I ask them to close their eyes (so they don't cheat) and point north. Many refuse; they do not know the answer. Those who do point take a while to think about it and then aim in all possible directions. I have repeated this exercise at Harvard and Princeton and in Moscow, London and Beijing, always with the same results.

A five-year-old in one culture can do something with ease that eminent scientists in other cultures struggle with. This is a big difference in cognitive ability. What could explain it? The surprising answer, it turns out, may be language.

The notion that different languages may impart different cognitive skills goes back centuries. Since the 1930s it has become associated with American linguists Edward Sapir and Benjamin Lee Whorf, who studied how languages vary and proposed ways that speakers of different tongues may think differently. Although their ideas met with much excitement early on, there was one small problem: a near complete lack of evidence to support their claims. By the 1970s many scientists had become disenchanted with the Sapir-Whorf hypothesis, and it was all but abandoned as a new set of theories claiming that language and thought are universal muscled onto the scene. But now, decades later, a solid body of empirical evidence showing how languages shape thinking has finally emerged. The evidence overturns the long-standing dogma about universality and yields fascinating insights into the origins of knowledge and the construction of reality. The results have important implications for law, politics and education.

IN BRIEF

People communicate using a multitude of languages that vary considerably in the information they convey.
Scholars have long wondered whether different languages might impart different cognitive abilities.
In recent years empirical evidence for this causal relation has emerged, indicating that one's mother tongue does indeed mold the way one thinks about many aspects of the world, including space and time.
The latest findings also hint that language is part and parcel of many more aspects of thought than scientists had previously realized.

Illustration by Tom Whalen

UNDER THE INFLUENCE

AROUND THE WORLD people communicate with one another using a dazzling array of languages—7,000 or so all told—and each language requires very different things from its speakers. For example, suppose I want to tell you that I saw *Uncle Vanya* on 42nd Street. In Mian, a language spoken in Papua New Guinea, the verb I used would reveal whether the event happened just now, yesterday or in the distant past, whereas in Indonesian, the verb wouldn't even give away whether it had already happened or was still coming up. In Russian, the verb would reveal my gender. In Mandarin, I would have to specify whether the titular uncle is maternal or paternal and whether he is related by blood or marriage, because there are different words for all these different types of uncles and then some (he happens to be a mother's brother, as the Chinese translation clearly states). And in Pirahã, a language spoken in the Amazon, I couldn't say "42nd," because there are no words for exact numbers, just words for "few" and "many."

Languages differ from one another in innumerable ways, but just because people talk differently does not necessarily mean they think differently. How can we tell whether speakers of Mian, Russian, Indonesian, Mandarin or Pirahã actually end up attending to, remembering and reasoning about the world in different ways because of the languages they speak? Research in my lab and in many others has been uncovering how language shapes even the most fundamental dimensions of human experience: space, time, causality and relationships to others.

Let us return to Pormpuraaw. Unlike English, the Kuuk Thaayorre language spoken in Pormpuraaw does not use relative spatial terms such as left and right. Rather Kuuk Thaayorre speakers talk in terms of absolute cardinal directions (north, south, east, west, and so forth). Of course, in English we also use cardinal direction terms but only for large spatial scales. We would not say, for example, "They set the salad forks southeast of the dinner forks—the philistines!" But in Kuuk Thaayorre cardinal directions are used at all scales. This means one ends up saying things like "the cup is southeast of the plate" or "the boy standing to the south of Mary is my brother." In Pormpuraaw, one must always stay oriented, just to be able to speak properly.

Moreover, groundbreaking work conducted by Stephen C. Levinson of the Max Planck Institute for Psycholinguistics in Nijmegen, the Netherlands, and John B. Haviland of the University of California, San Diego, over the past two decades has demonstrated that people who speak languages that rely on absolute directions are remarkably good at keeping track of where they are, even in unfamiliar landscapes or inside unfamiliar buildings. They do this better than folks who live in the same environments but do not speak such languages and in fact better than scientists thought humans ever could. The requirements of their languages enforce and train this cognitive prowess.

People who think differently about space are also likely to think differently about time. For example, my colleague Alice Gaby of the University of California, Berkeley, and I gave Kuuk Thaayorre speakers sets of pictures that showed temporal progressions—a man aging, a crocodile growing, a banana being eaten. We then asked them to arrange the shuffled photographs on the ground to indicate the correct temporal order.

Speakers of different languages differ in how well they can remember who did what.

We tested each person twice, each time facing in a different cardinal direction. English speakers given this task will arrange the cards so that time proceeds from left to right. Hebrew speakers will tend to lay out the cards from right to left. This shows that writing direction in a language influences how we organize time. The Kuuk Thaayorre, however, did not routinely arrange the cards from left to right or right to left. They arranged them from east to west. That is, when they were seated facing south, the cards went left to right. When they faced north, the cards went from right to left. When they faced east, the cards came toward the body, and so on. We never told anyone which direction they were facing—the Kuuk Thaayorre knew that already and spontaneously used this spatial orientation to construct their representations of time.

Representations of time vary in many other ways around the world. For example, English speakers consider the future to be "ahead" and the past "behind." In 2010 Lynden Miles of the University of Aberdeen in Scotland and his colleagues discovered that English speakers unconsciously sway their bodies forward when thinking about the future and back when thinking about the past. But in Aymara, a language spoken in the Andes, the past is said to be in front and the future behind. And the Aymara speakers' body language matches their way of talking: in 2006 Raphael Núñez of U.C.S.D. and Eve Sweetser of U.C. Berkeley found that Aymara gesture in front of them when talking about the past and behind them when discussing the future.

REMEMBERING WHODUNIT

SPEAKERS OF DIFFERENT LANGUAGES also differ in how they describe events and, as a result, how well they can remember who did what. All events, even split-second accidents, are complicated and require us to construe and interpret what happened. Take, for example, former vice president Dick Cheney's quail-hunting accident, in which he accidentally shot Harry Whittington. One could say that "Cheney shot Whittington" (wherein Cheney is the direct cause), or "Whittington got shot by Cheney" (distancing Cheney from the outcome), or "Whittington got peppered pretty good" (leaving Cheney out altogether). Cheney himself said "Ultimately I'm the guy who pulled the trigger that fired the round that hit Harry," interposing a long chain of events between himself and the outcome. President George Bush's take—"he heard a bird flush, and he turned and pulled the trigger and saw his friend get wounded"—was an even more masterful exculpation, transforming Cheney from agent to mere witness in less than a sentence.

The American public is rarely impressed with such linguistic wiggling because nonagentive language sounds evasive in English, the province of guilt-shirking children and politicians. English speakers tend to phrase things in terms of people doing things, preferring transitive constructions like "John broke the vase" even for accidents. Speakers of Japanese or Spanish, in contrast, are less likely to mention the agent when describing an accidental event. In Spanish one might say "*Se rompió el florero,*" which translates to "the vase broke" or "the vase broke itself."

My student Caitlin M. Fausey and I have found that such linguistic differences influence how people construe what happened and have consequences for eyewitness memory. In our studies, published in 2010, speakers of English, Spanish and

Japanese watched videos of two guys popping balloons, breaking eggs and spilling drinks either intentionally or accidentally. Later we gave them a surprise memory test. For each event they had witnessed, they had to say which guy did it, just like in a police line-up. Another group of English, Spanish and Japanese speakers described the same events. When we looked at the memory data, we found exactly the differences in eyewitness memory predicted by patterns in language. Speakers of all three languages described intentional events agentively, saying things such as "He popped the balloon," and all three groups remembered who did these intentional actions equally well. When it came to accidents, however, interesting differences emerged. Spanish and Japanese speakers were less likely to describe the accidents agentively than were English speakers, and they correspondingly remembered who did it less well than English speakers did. This was not because they had poorer memory overall—they remembered the agents of intentional events (for which their languages would naturally mention the agent) just as well as English speakers did.

Not only do languages influence what we remember, but the structures of languages can make it easier or harder for us to learn new things. For instance, because the number words in some languages reveal the underlying base-10 structure more transparently than do the number words in English (there are no troublesome teens like 11 or 13 in Mandarin, for instance), kids learning those languages are able to learn the base-10 insight sooner. And depending on how many syllables the number words have, it will be easier or harder to keep a phone number in mind or to do mental calculation. Language can even affect how quickly children figure out whether they are male or female. In 1983 Alexander Guiora of the University of Michigan at Ann Arbor compared three groups of kids growing up with Hebrew, English or Finnish as their native language. Hebrew marks gender prolifically (even the word "you" is different depending on gender), Finnish has no gender marking and English is somewhere in between. Accordingly, children growing up in a Hebrew-speaking environment figure out their own gender about a year earlier than Finnish-speaking children; English-speaking kids fall in the middle.

ADDITIONAL RESOURCES
ScientificAmerican.com/feb2011/language

WHAT SHAPES WHAT?

These are just some of the many fascinating findings of cross-linguistic differences in cognition. But how do we know whether differences in language create differences in thought, or the other way around? The answer, it turns out, is both—the way we think influences the way we speak, but the influence also goes the other way. The past decade has seen a host of ingenious demonstrations establishing that language indeed plays a causal role in shaping cognition. Studies have shown that changing how people talk changes how they think. Teaching people new color words, for instance, changes their ability to discriminate colors. And teaching people a new way of talking about time gives them a new way of thinking about it.

Another way to get at this question is to study people who are fluent in two languages. Studies have shown that bilinguals change how they see the world depending on which language they are speaking. Two sets of findings published in 2010 demonstrate that even something as fundamental as who you like and do not like depends on the language in which you are asked. The studies, one by Oludamini Ogunnaike and his colleagues at Harvard and another by Shai Danziger and his colleagues at Ben-Gurion University of the Negev in Israel, looked at Arabic-French bilinguals in Morocco, Spanish-English bilinguals in the U.S. and Arabic-Hebrew bilinguals in Israel, in each case testing the participants' implicit biases. For example, Arabic-Hebrew bilinguals were asked to quickly press buttons in response to words under various conditions. In one condition if they saw a Jewish name like "Yair" or a positive trait like "good" or "strong," they were instructed to press "M,"; if they saw an Arab name like "Ahmed" or a negative trait like "mean" or "weak," they were told to press "X." In another condition the pairing was reversed so that Jewish names and negative traits shared a response key, and Arab names and positive traits shared a response key. The researchers measured how quickly subjects were able to respond under the two conditions. This task has been widely used to measure involuntary or automatic biases—how naturally things such as positive traits and ethnic groups seem to go together in people's minds.

Surprisingly, the investigators found big shifts in these involuntary automatic biases in bilinguals depending on the language in which they were tested. The Arabic-Hebrew bilinguals, for their part, showed more positive implicit attitudes toward Jews when tested in Hebrew than when tested in Arabic.

Language also appears to be involved in many more aspects of our mental lives than scientists had previously supposed. People rely on language even when doing simple things like distinguishing patches of color, counting dots on a screen or orienting in a small room: my colleagues and I have found that limiting people's ability to access their language faculties fluently—by giving them a competing demanding verbal task such as repeating a news report, for instance—impairs their ability to perform these tasks. This means that the categories and distinctions that exist in particular languages are meddling in our mental lives very broadly. What researchers have been calling "thinking" this whole time actually appears to be a collection of both linguistic and nonlinguistic processes. As a result, there may not be a lot of adult human thinking where language does not play a role.

A hallmark feature of human intelligence is its adaptability, the ability to invent and rearrange conceptions of the world to suit changing goals and environments. One consequence of this flexibility is the great diversity of languages that have emerged around the globe. Each provides its own cognitive toolkit and encapsulates the knowledge and worldview developed over thousands of years within a culture. Each contains a way of perceiving, categorizing and making meaning in the world, an invaluable guidebook developed and honed by our ancestors. Research into how the languages we speak shape the way we think is helping scientists to unravel how we create knowledge and construct reality and how we got to be as smart and sophisticated as we are. And this insight, in turn, helps us understand the very essence of what makes us human. SA

MORE TO EXPLORE

Language Changes Implicit Associations between Ethnic Groups and Evaluation in Bilinguals. Shai Danziger and Robert Ward in *Psychological Science,* Vol. 21, No. 6, pages 799–800; June 2010.

Constructing Agency: The Role of Language. Caitlin M. Fausey et al. in *Frontiers in Cultural Psychology,* Vol. 1, Article 162. Published online October 15, 2010.

Remembrances of Times East: Absolute Spatial Representations of Time in an Australian Aboriginal Community. Lera Boroditsky and Alice Gaby in *Psychological Science,* Vol. 21, No. 11, pages 1635–1639; November 2010.

BIOLOGY

The Inner Life of the Genome

The way our genes are arrayed and move in the 3-D space of the cell nucleus turns out to profoundly influence how they function, in both health and disease

By Tom Misteli

IN BRIEF

Chromosomes are not sprinkled randomly around the inside of the nucleus. They occupy preferred positions.

This nuclear organization reflects the functional state of each chromosome and of the genes it carries. The organization can change as a cell's behavior changes and in disease.

Identifying the locations that genes occupy within the nucleus—and seeing how these positions change under different conditions—is providing clues to how normal cells function and how some diseases, including cancer, arise.

Chromosomes in a dividing cell (*left*) are duplicated and highly compact. At other times, though, they are singletons and more expanded (*below*). Until the recent advent of "chromosome painting" techniques, the expanded chromosomes were difficult to distinguish from one another.

Illustrations by Anatomy Blue

Tom Misteli is a senior investigator at the National Cancer Institute in Bethesda, Md. Aided by imaging tools he developed, his laboratory is working to uncover fundamental principles of three-dimensional genome organization in the nucleus of living cells and to apply this knowledge to discovering new strategies for addressing cancer and aging.

TEN YEARS AGO PUBLICATION OF THE HUMAN GENOME sequence gave the world a blueprint for a human being. But just as a list of automobile parts does not tell us how a car engine works, the complete genome sequence—a list of the DNA "letters" in all the chromosomes of the human cell—did not reveal how the genome directs our cells' day-to-day activities or allows an individual to develop from a fertilized egg into a functioning adult.

To better understand the way the genome as a whole orchestrates the symphony of biological activity called life, I and others in the new field of genome cell biology are examining how chromosomes, and the genes they house, are arranged within the three-dimensional space of the nucleus and how that organization influences their activities.

Aided by new 3-D imaging technology that allows us to peer deeper than ever into the living cell, we have discovered a startlingly vibrant ecosystem. In the nucleus, chromosomes physically interact with neighboring chromosomes, genes on those chromosomes migrate to different nuclear locations depending on what they need to accomplish, and molecules that regulate gene activity congregate in bustling hubs. These new discoveries offer fresh insights into how our genomes maintain our health and how some diseases, including certain cancers, arise; they may also lead to new ways of diagnosing disease.

EARLY QUESTIONS

THE RECENT PROGRESS grows out of discoveries made in the 1980s. Back then, biologists knew that chromosomes become highly condensed during cell division, taking on the hourglass-shaped structure that most of us picture when we think about the entities that carry our genes from one generation to the next. They also knew that chromosomes have a looser shape when cells are not dividing and are going about their usual business. That relaxed appearance made it hard to discern chromosomes individually even with the very best microscopes, and prevailing opinion held that chromosomes in nondividing cells intermix like spaghetti jumbled up in a bowl.

That view was prevalent in spite of some hints to the contrary. In the early 1900s a German cell scientist named Theodor Boveri had objected to this "spaghetti model" of chromosome organization. Based on studies he had conducted with a kind of roundworm that infects horses, he argued that, although a chromosome could undergo changes in size and shape throughout the life of a cell, each chromosome occupies a distinct, well-defined area of the nucleus. He christened the regions inhabited by these individual chromosomes as "chromosome territories." But because chromosomes were difficult to see—and because Boveri's roundworms were not a typical experimental system—his concept of chromosome territories long remained marginalized.

Definitive experimental evidence for the chromosome territory idea came only when two other Germans, the brothers Thomas and Christoph Cremer, developed a method for marking and visualizing the genetic material in a small region of the nucleus. In the early 1980s the Cremers showed that when a laser beam hits DNA in a particular area of the nucleus, only a few chromosomes come away branded. If nuclear DNA were as jumbled together as had been previously believed, each laser pulse would have struck many more chromosomes.

A few years later investigators perfected a more targeted and colorful method for tagging and visualizing whole chromosomes. This approach—dubbed chromosome painting—attaches fluorescently labeled tags to sequences of DNA code letters in individual chromosomes. Each chromosome can be tagged with a specific fluorescent marker and its location pinpointed. These studies demonstrated unambiguously that chromosomes exist in the nucleus as distinct entities, occupying a space separate from other chromosomes [*see micrograph on opposite page*].

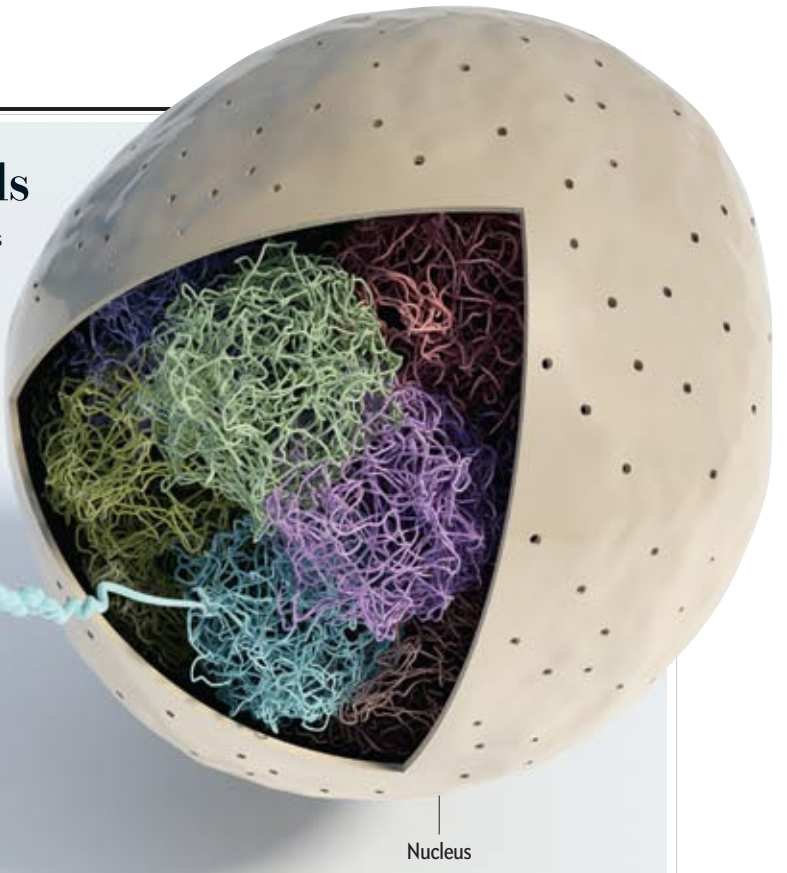
This finding raised many questions, now being addressed by genome cell biologists. Are chromosomes scattered randomly throughout the nucleus, like attendees at an event with open seating? Or do chromosomes have "assigned seats" within the nucleus? And more important, does their position affect the activity of the genes they harbor?

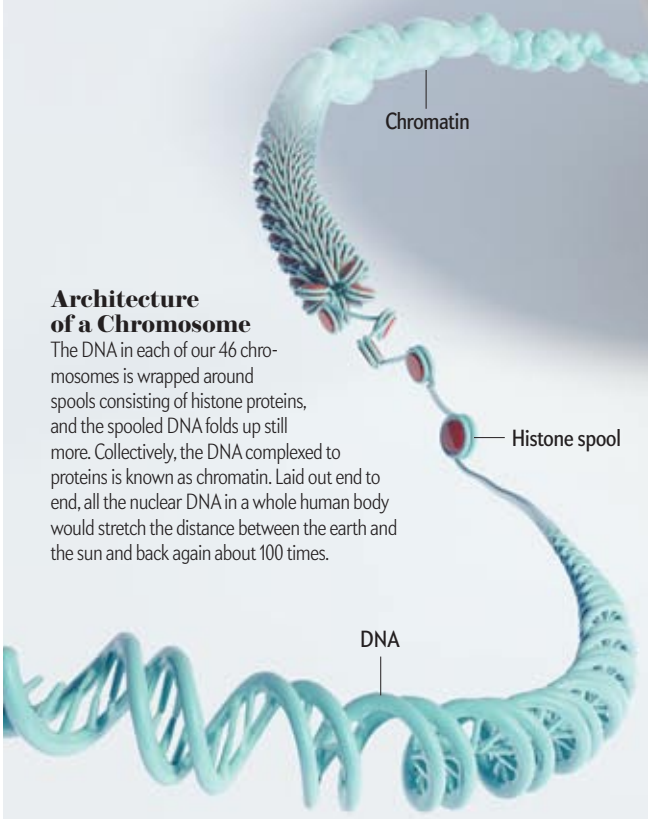
FAVORED NEIGHBORHOODS

WE NOW KNOW that individual chromosomes tend to occupy preferred locations inside the nucleus. In human white blood cells, for example, chromosome 18 generally hugs the outer wall of

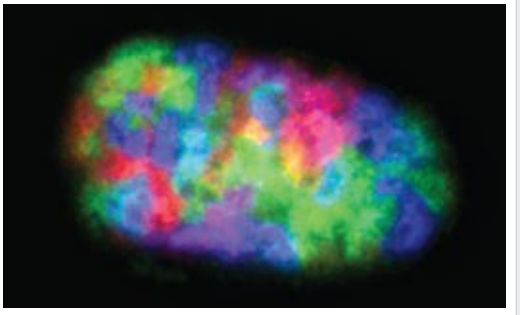
Organized at Many Levels

Biologists have long known that the DNA in chromosomes folds up in complex ways (*diagram*). They have now also demonstrated that individual chromosomes occupy distinct territories in the nucleus (*micrograph*) and that some chromosomes prefer the nuclear periphery, whereas others like to cluster closer to the core. Moreover, where chromosomes reside, and which chromosomes lie near one another, can strongly influence how cells function.





Architecture of a Chromosome
The DNA in each of our 46 chromosomes is wrapped around spools consisting of histone proteins, and the spooled DNA folds up still more. Collectively, the DNA complexed to proteins is known as chromatin. Laid out end to end, all the nuclear DNA in a whole human body would stretch the distance between the earth and the sun and back again about 100 times.



Architecture of a Nucleus
In the past 15 years advanced microscopy has given the lie to a long-standing view that chromosomes sit higgledy-piggledy in the cell nucleus, like cooked spaghetti in a bowl. This image individually colors the chromosomes in the nucleus of a human fibroblast.

FROM "COBRA: COMBINED BINARY RATIO LABELING OF NUCLEIC-ACID PROBES FOR MULTI-COLOR FLUORESCENCE IN SITU HYBRIDIZATION KARYOTYPING," BY KAROLY SZUHAI AND HANS J. TANKE, IN *NATURE PROTOCOLS*, VOL. 1, NO. 1; JUNE 2006 (*micrograph*)

the nucleus, whereas chromosome 19 prefers to remain in the center; chromosome 7, meanwhile, tends to hover somewhere in between. The tendency of each chromosome to assume a preferred position either closer to—or farther from—the nuclear edge also creates distinct neighborhoods throughout the nucleus. Consequently, each chromosome has a set of neighbors that is usually consistent from one cell to another within a given type. In studies of mouse white blood cells, for instance, my colleagues and I found that chromosome 12 often clusters with chromosomes 14 and 15.

Chromosome positions are not etched in stone, however. My laboratory discovered that chromosomes are arrayed differently in different cell types, and other researchers have found that these arrangements change during development and in disease. What is more, where a chromosome lives seems to influence whether the genes it carries are turned on or off.

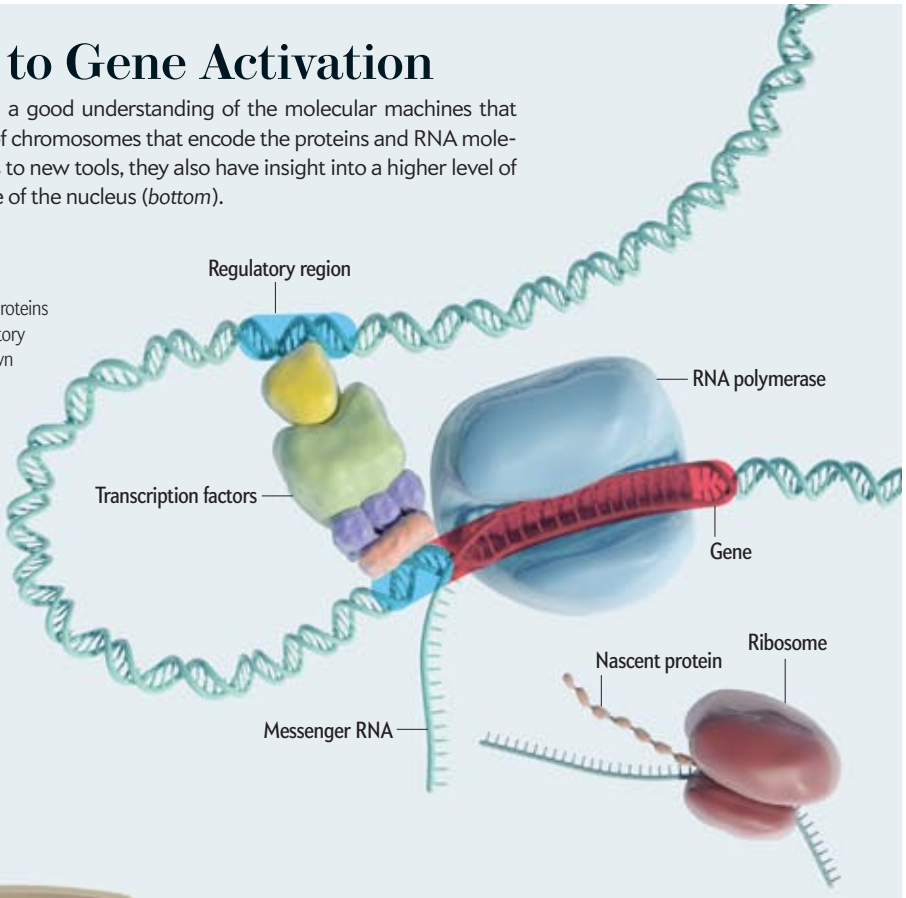
A hint that a gene's location within the nucleus might be important for its activity came from the finding that some genes change their positions when their activity changes. One example comes from studies that tracked a gene called *GFAP*. Star-shaped brain cells called astrocytes typically have one active copy of the gene (the copy used to make a protein specified by the gene) and one silent copy. Takumi Takizawa in my lab discovered that the silent version generally lies toward the periph-

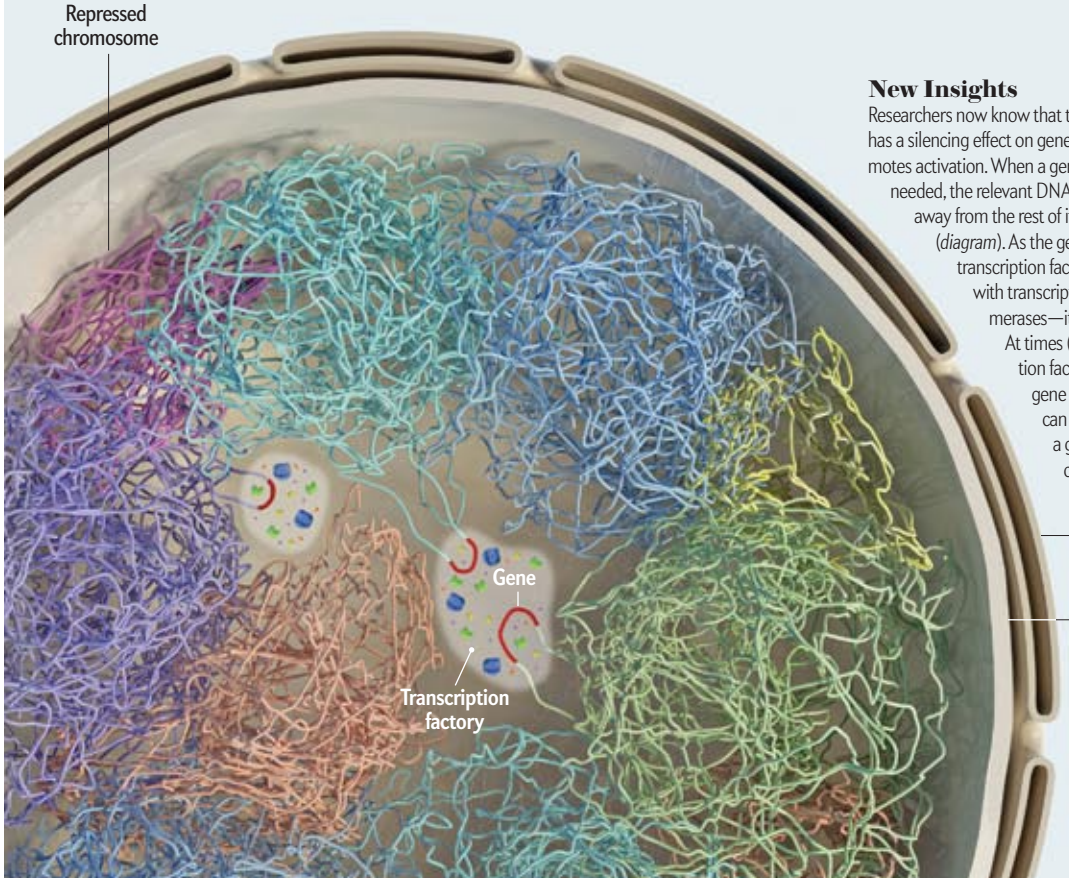
Fresh Clues to Gene Activation

For many years investigators have had a good understanding of the molecular machines that switch on genes (*top image*), the parts of chromosomes that encode the proteins and RNA molecules produced in cells. But now, thanks to new tools, they also have insight into a higher level of control: that exerted by the architecture of the nucleus (*bottom*).

Basics of Gene Activation

A gene gets switched on, or read out, after proteins called transcription factors collect on regulatory regions of the gene, enabling enzymes known as RNA polymerases to transcribe the gene's DNA code letters, or nucleotides, into mobile RNA copies. In the case of protein-coding genes, the RNA molecules, known as messenger RNAs, migrate to the cytoplasm, where structures called ribosomes translate them into the specified proteins.





New Insights

Researchers now know that the nuclear periphery has a silencing effect on genes, and the center promotes activation. When a gene that is quiet is needed, the relevant DNA is thought to loop away from the rest of its chromosome (*diagram*). As the gene finds itself in a transcription factory—a zone buzzing with transcription factors and polymerases—it becomes fully active. At times (*not shown*), transcription factors attached to a gene on one chromosome can actually help activate a gene on a nearby chromosome.

ery of the nucleus, whereas the active copy resides in the nuclear interior. Others have found a similar positioning for genes that encode the defensive antibodies, or immunoglobulins, that white blood cells secrete when provoked by an invader. In white blood cells that have been placed on alert by foreign cells, the region of the chromosome that houses the *IGH* gene, which encodes an immunoglobulin component, tends to move to a more central position in the nucleus. Together, such discoveries have pointed to a simple rule of how the position of a gene affects its function: genes at the periphery of the nucleus are often inactive.

Might something in the outer flanks of the nucleus favor gene silencing? An early sign that the answer is yes was the observation, made in the 1930s, that the nuclear periphery is lined with heterochromatin—chromosomal regions that are highly condensed. If you had supernatural vision and could look inside a chromosomes, you would see that it consists of double-helical DNA that is wrapped around spools composed of proteins called histones and that this spooled DNA folds in on itself to form a thick fiber called chromatin [*see illustration on page 69*]. Chromatin fibers themselves fold up even further, becoming increasingly condensed. Heterochromatin is a special form of chromatin that is coiled particularly tightly, an arrangement that generally prevents gene-reading proteins from accessing the underlying DNA.

Chromosomes are arrayed differently in different cell types, and these arrangements change during development. Where a chromosome lives seems to influence whether the genes it harbors are on or off.

Of course, that early observation could not reveal whether the periphery promotes silencing—or whether compacted chromatin is attracted to that area for other reasons. But a set of elegant experiments, conducted by several labs in 2008, favors the first view. When researchers removed active genes from their regular location in the nuclear interior and tethered them to the membrane that surrounds the nucleus, their activity was generally reduced. So the nuclear periphery helps to keep at least some genes quiet.

The nuclear interior, for its part, might also offer something special to chromosomes and genes whose activity is required quickly or often: collections of protein conglomerates known as transcription factories. These "factories" are aggregations of the cellular components required to activate genes, including polymerase enzymes (which transcribe DNA into RNA that is later translated into an encoded protein), as well as transcription factors (proteins that bind to regulatory areas of genes and start the polymerases on their way).

Peter Cook of the University of Oxford first proposed the existence of these factories in 1993, after noting that the number of active genes in the nucleus at any given time is much greater than the number of sites where polymerases are busy reading genes. An obvious way to explain this pattern would be the clustering of multiple genes in hubs of transcriptional activity, where they share polymerases and transcription factors [*see box on opposite page*]. The idea is not without precedent: hundreds of genes that encode ribosomal RNAs (vital parts of the cell's protein-producing machinery) are transcribed together in the nucleolus—a nuclear substructure large enough to see under a microscope.

GENOME CELL BIOLOGISTS have not yet learned all the rules governing the activity of genes in different parts of the nucleus. We have shown, however, that where genes reside in nuclear space has relevance to normal development and to health.

A particularly striking instance of how gene organization changes during normal embryonic development has emerged from studies of the embryonic stem cells. These cells are "pluripotent" generalists, possessing the unique ability to differentiate into any one of the 220 or so specialized tissues in the body, such as nerve cells, blood cells or muscle. Unlike fully differentiated cells, these functionally flexible embryonic stem cells lack the large regions of heterochromatin in which genes are silenced. They also lack proteins called lamins that help to tether inactive DNA to the nuclear periphery. As a result, just about every gene in a stem cell genome is active at a low level.

When embryonic stem cells receive a signal to differentiate into, say, bone cells or neurons, their nuclear architecture changes dramatically. Lamin proteins appear and join together to form a tight, interwoven mat—the nuclear lamina—that sits under the nuclear membrane. This supportive lamina is believed to maintain nuclear shape and to protect the chromosomes from external mechanical pressure. But it also appears to be involved in normal gene regulation. Chromosome segments that have fewer active genes contain a particular structural protein that compresses those regions into heterochromatin—and ties them to the lamin proteins in the outskirts of the nucleus. That sequestration leaves the gene-rich areas closer to the interior and to the gene factories that allow them to be active. Thus, the appearance of lamins during embryonic development allows cells to shut down genes that are no longer needed, by banishing them to the sidelines.

That this exiling of selected chromosomal regions may be critical for proper gene functioning in differentiated cells is supported by observations of what happens when lamins are abnormal. Mutations in lamins lead to a variety of human disorders, ranging from muscular dystrophies and neurological disorders to premature aging. This collection of so-called laminopathies is unusual in its breadth: in contrast to most conditions—in which any mutation in a given gene leads to the same disease—mutations in lamins cause an unusually broad spectrum of illnesses. Cell biologists are not sure how defective lamins cause these disorders. One possibility is that they weaken the lamina, leaving it unable to shield the nucleus from mechanical forces, with the consequence that much of the genome in vulnerable cells becomes physically damaged, perhaps leading to the cell's death. Another intriguing idea is that defective lamin proteins may be compromised in their ability to organize the genome, thus placing genes in the wrong places and potentially disrupting their normal functioning.

Studies that have mapped the positions of chromosomes in cells from patients with lamin-based disorders tend to support this last theory: one investigation showed an abnormal relocation of chromosomes 13 and 18—from the periphery to the inte-

rior—in cells harboring a lamin disease mutation. Not yet clear, though, is whether this chromosomal repositioning is a consequence of the disease or a contributing factor.

Chromosomal positioning plays a more clearly central role in some cancers. Malignant cells often contain chromosomal "translocations"—abnormal chromosomes that form when a segment breaks off one chromosome and becomes attached to another [*see box on opposite page*]. In some cases, such translocations cause cancer because the fusion creates a mutant gene that promotes excessive cell proliferation; in other cases, they are simply bystanders.

As it turns out, which chromosomes combine to form cancer-promoting translocations is influenced by where the chromosomes reside in the nucleus: chromosomes that are found together in the nucleus tend to fuse more frequently. Consider Burkitt's lymphoma. Many patients with this disease have a translocation between the *MYC* gene, located on chromosome 8, and the *IGH* gene, on chromosome 14; in rare cases, *MYC* translocates with a different immunoglobulin gene on chromosome 2, called *IGK*, and even more rarely with the *IGL* gene, on chromosome 22. In 2003 Jeffrey Roix in my lab discovered that the average distance in the nucleus between *MYC* and its three translocation partners corresponds precisely to their translocation frequencies, suggesting a link between gene distance and probability of translocation. The same link has since been found for a number of other cancers.

My lab has also shown that when a chromosome breaks, the damaged ends remain close to home and do not stray far from where they were situated at the time of breakage. This observation explains why chromosomes clustered in the same neighborhood have a greater probability of fusing than distant chromosomes do. It explains, too, why specific translocations are a hallmark of cancers that arise in one tissue but not another: because chromosomes are arranged differently in different tissues. Thus, chromosomes that cluster near one another in, say, kidney cells, would be more likely to be translocation partners in kidney tumors than in cancers of other tissues, such as white blood cells, where they normally lie farther apart.

One of the most exciting developments in the field has been the realization that knowledge of where chromosomes typically reside in the nucleus might present opportunities for cancer detection. Preliminary experiments have demonstrated that the position of genes can help indicate whether a cell is cancerous. In a pilot study of breast cancer, Karen Meaburn in my lab identified several genes whose positions differed in tumor cells as compared with cells from normal breast tissue. These genes turned out to be good markers for breast cancer: they allowed us to pick out cancerous tissue samples with very high accuracy. In malignant cells, some genes change position even before the cells begin behaving badly. We have reason to hope, therefore, that gene-position analyses will one day become a powerful molecular tool for helping physicians to diagnose cancer at very early stages.

One of the most exciting developments has been the realization that knowledge of where chromosomes typically reside in the nucleus might present opportunities for cancer detection.

INTERVIEW WITH THE AUTHOR
ScientificAmerican.com/feb2011/genome

THE SELF-ORGANIZED NUCLEUS

THE HOLY GRAIL in the field of genome cell biology is the question of what determines where a gene or a chromosome is positioned in the nucleus. How do genes and chromosomes know where to go—and how do they get there as the cells in which they reside differentiate into their specialized states?

One theoretical possibility is that chromosomal sequences get escorted to their proper destinations by specific cellular machinery. Perhaps a DNA-binding protein that recognizes a specific gene sequence attaches to that sequence and then—with the help of a molecular motor protein—drags that part of the chromosome to a particular site in the nucleus. But so far no one has identified such a system. And it is hard to imagine a signaling system that could communicate a set of geographic coordinates to a piece of DNA, directing a gene to loiter near the nuclear center or to pay a visit to its favorite transcription factory.

Instead I have proposed that nuclear positioning is self-organizing, somewhat like middle school students forming cliques because they are drawn together by mutual interests, not because they were instructed to associate by parents or teachers. In this view, the location of genes and chromosomes inside the nucleus springs from their activity and is not determined by some external organizing machinery. In turn, their location then influences their activity.

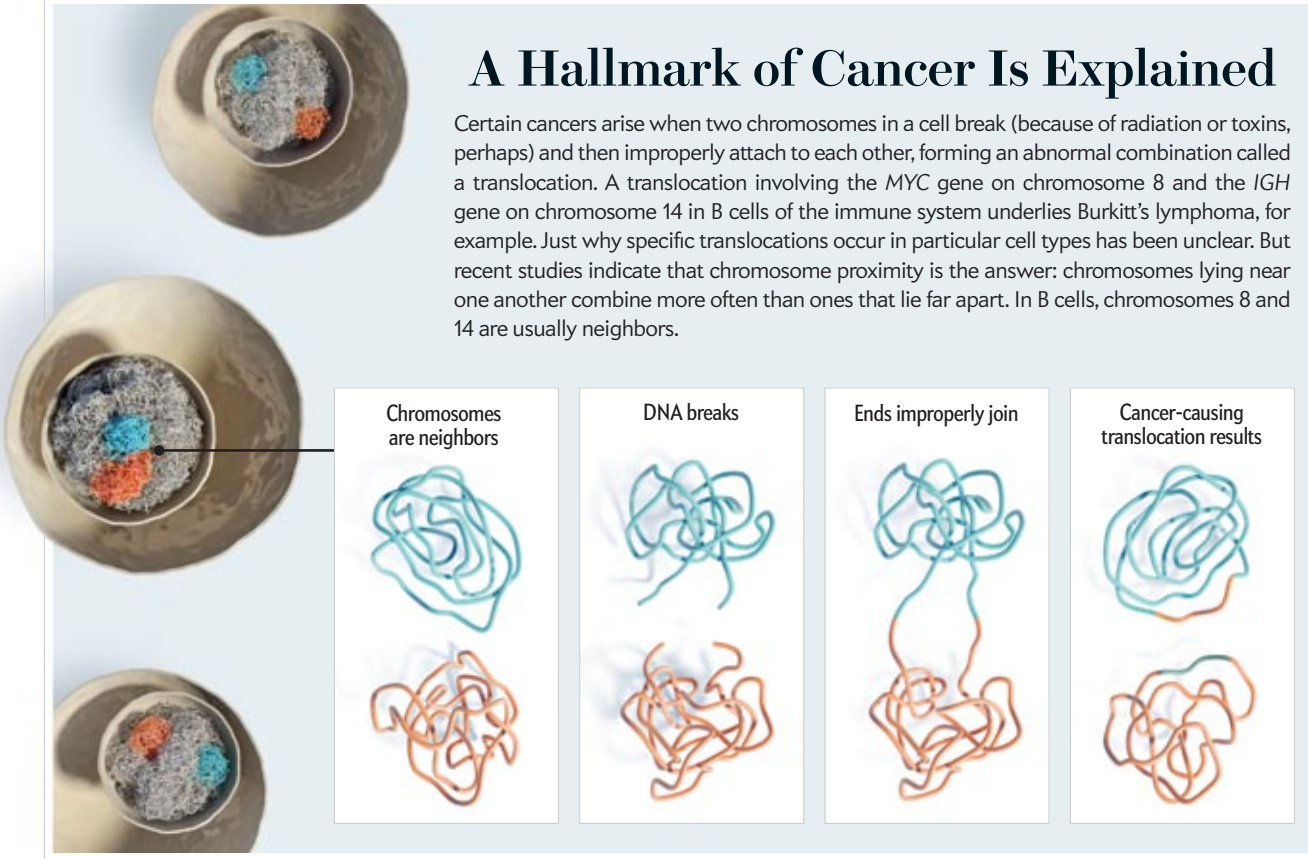
How would this self-organization work? Let us follow what happens in a self-organizing nucleus when an individual gene in a differentiated cell is turned on in response to a signal, say, a hormone. Before the signal reaches the cell, the gene is inactive—most likely tucked away in a section of condensed chromatin, perhaps even in a block of heterochromatin hugging the nuclear periphery. When the signal arrives in the nucleus, molecules known as chromatin remodeling complexes unfold the condensed DNA in and around the gene and make the region more accessible to the transcriptional machinery. In a self-organizing nucleus, this relaxation would allow that stretch of chromatin to loop out from the heterochromatin in the periphery and to flop around, exploring new parts of the nucleus. With any luck, the meandering loop will eventually make contact with a transcription factory.

Note that this movement of the gene—from the nuclear outskirts to the center of the action—occurs without the help of a dedicated transport machinery and is entirely driven by the activity of the gene itself. Thus, the position of the gene is self-determined. This model has an intriguing consequence: it suggests that although a gene's nuclear location is not random, how it gets there can be.

The self-organization concept agrees with many results from gene-tracking experiments. Genes can loop out from chromosomes and travel through the nucleus. A few genes even take this transcriptional ticket-to-wander to an extreme. When white blood cells are stimulated by hormones called cytokines, genes that encode immune system proteins known as MHC class II molecules stray far away from the body of the chromosome on

A Hallmark of Cancer Is Explained

Certain cancers arise when two chromosomes in a cell break (because of radiation or toxins, perhaps) and then improperly attach to each other, forming an abnormal combination called a translocation. A translocation involving the *MYC* gene on chromosome 8 and the *IGH* gene on chromosome 14 in B cells of the immune system underlies Burkitt's lymphoma, for example. Just why specific translocations occur in particular cell types has been unclear. But recent studies indicate that chromosome proximity is the answer: chromosomes lying near one another combine more often than ones that lie far apart. In B cells, chromosomes 8 and 14 are usually neighbors.



which they are located—sometimes stretching halfway across the nucleus.

The same principle may govern the positioning of entire chromosomes. Although most genes are rather subtle in their movement, each makes a small contribution to where its chromosome will wind up in the cell. So if self-organization is the rule, one would expect a chromosome that contains mostly inactive genes will find itself pulled toward the more repressive regions in the nuclear periphery, whereas a chromosome having predominantly active genes will be dragged toward the nuclear interior.

To test this prediction, Mark Groudine and his colleagues at the Fred Hutchinson Cancer Center in Seattle collected blood precursor cells and then triggered their maturation. At different points, cells were harvested, and the activities of several thousand genes were measured. At the same time, the investigators monitored the position of the chromosomes on which these genes were located. The results: the chromosomes that harbored the largest number of genes whose activity changed as the cells matured showed the most movement.

These experiments are a good start, but they are difficult, because it is tedious to simultaneously monitor the position of many genome regions microscopically. A potentially revolutionary method, dubbed Hi-C, may soon solve this problem. This approach, developed by Job Dekker of the University of Massachusetts Medical School, gives an instantaneous snapshot of the three-dimensional architecture of the genome by chemically tying together all the chromosomal regions that touch one another in the nucleus. Using Hi-C, biologists should soon be able to determine the locations of chromosomes in nuclei from different tissues at different times and under different conditions—and, by comparing these patterns with the sets of active and inactive genes, obtain unprecedented insight into how nuclear organization influences function and how disruptions contribute to disease.

Producing the first draft of the human genome sequence took about 10 years of massive effort. Genome cell biologists, driven to learn more than sequence alone can reveal, are just beginning to uncover the ways genomes behave in their natural habitat of the cell. This task, though exhilarating, is formidable. Given its complexity, it will likely occupy biologists far longer than it took to sequence the human genome in the first place. SA

MORE TO EXPLORE

The Cell Nucleus and Aging: Tantalizing Clues and Hopeful Promises. Paola Scaffidi, Leslie Gordon and Tom Misteli in *PLoS Biology,* Vol. 3, No. 11, e395; November 2005.

Cell Biology: Chromosome Territories. Karen J. Meaburn and Tom Misteli in *Nature,* Vol. 445, pages 379–381; January 25, 2007.

Beyond the Sequence: Cellular Organization of Genome Function. Tom Misteli in *Cell,* Vol. 128, No. 4, pages 787–800; February 2007.

Dynamic Genome Architecture in the Nuclear Space: Regulation of Gene Expression in Three Dimensions. Christian Lanctôt et al. in *Nature Reviews Genetics,* Vol. 8, No. 2, pages 104–115; February 2007.

Comprehensive Mapping of Long-Range Interactions Reveals Folding Principles of the Human Genome. Erez Lieberman-Aiden et al. in *Science,* Vol. 326, pages 289–293; October 9, 2009.

The Nucleus. Edited by Tom Misteli and David L. Spector. Cold Spring Harbor Laboratory Press, 2010.

ECOLOGY

A Friend to Aliens

Buckthorn, garlic mustard and many other invasive species do not pose as big a threat as some scientists think, says ecologist Mark Davis

Interview by Brendan Borrell

PLANT ECOLOGIST MARK A. DAVIS WILL NOT PARTICIPATE in this year's "Buckthorn Roundups" around his St. Paul, Minn., neighborhood. Davis will not tag along as these intrepid crusaders set out to eradicate the common and glossy buckthorn, two ornamental shrubs imported in the 19th century from Europe. The nonnatives have now taken over some Midwestern forests, prairies and wetlands. That is why eco-minded volunteers eagerly wrench young weeds from the soil, hack away at thick stems and douse remaining stumps with herbicides. Their hope: a return of Minnesota to its primeval state.

At one time, Davis, too, could see the logic in eradicating these "invaders." He even advocated planting only Minnesota native plants on the Macalester College campus where he teaches. That changed in 1994, when he read an essay by journalist Michael Pollan in the *New York Times Magazine* that made his blood boil. He bristled at Pollan's statement that turning the "ecological clock to 1492 is a fool's errand, futile and pointless to boot."

After Davis cooled down, he started to think carefully about the problem. Gradually, he reconsidered his assumptions and developed a more nuanced position on the threat from nonnative species. In line with his new view, he gave benign nonnatives the name "LTLs"—as in something we should "Learn to Live" with—which vexed some colleagues. He argues here, as he does in his book *Invasion Biology* (Oxford University Press, 2009), that the field needs less emotion and more science. The transcript has been edited for clarity.

IN BRIEF

Migration of plants, animals and other species outside their native ecological niches represents a danger overhyped by some ecologists, contends a scientist who once decried such threats.

Mark Davis of Macalester College asserts that we should worry about invasive species only when they create a direct threat to health or economic well-being. Extinctions from invaders remain the exception. Nonnative species do not usually drive out plants and animals when they reach a new place.

Isolated places, such as islands, represent the one setting in which the nonnatives can frequently cause the endemic population to disappear.

Davis maintains that we simply must get used to the reality that species do not stay put.

Photograph by Amy Eckert

Scientific American: You've tried to establish yourself as a skeptic in the debate over the impacts of introduced species. What would you say makes particular species a problem?

Davis: A species is a problem when humans define it as a problem. Organisms are just organisms. They're not moral or ethical; they are just living. Good or bad, that's completely a human declaration. The problem I have is when species are not health threats, are not causing any significant economic cost, yet people claim they have undesirable ecological effects. And that's where I think it's very important that we challenge ourselves: "Wait a minute. Is this harm, or is this just change?" The fact that certain native species may become less abundant, is that really harm, or is that just change? It's socially irresponsible to call those changes harm. Once we declare something as invasive or harmful, it makes society obliged to reduce or mitigate this harm, which draws on scarce resources. I don't believe we can justify using social resources to support projects that are often little more than claims of personal preference.

Some critics of your argument would say that the introduction of the brown tree snake on the island of Guam, which has wiped out 10 bird species, is more than just change. That's irreversible damage.

I absolutely agree. The one environment where introduced species can and absolutely have caused lots of extinctions are in these insular environments such as oceanic islands or freshwater lakes. The species that cause those extinctions are almost always either a predator or a pathogen, and in these sorts of small, insular environments, there aren't any refuges for the prey or the host. So the introduced predator actually is able to wipe out prey. In those sorts of habitats, absolutely, introduced species are a major threat to species survival, and I certainly support dedicating resources to prevent that.

Are you suggesting that the impact of some nonnative species has been exaggerated?

Few nonnative species come close to causing the damage of the brown tree snake. We've been studying garlic mustard at the Macalester field station, and there's quite a bit of it that has spread into the oak forest. This past summer we sampled lots of plots and looked at the number of species that were in plots that had garlic mustard and the number in plots that didn't have garlic mustard. Now, what you generally hear about garlic mustard is that it's the evil enemy, pushing out the native species. In fact, we found no relationship between the abundance of garlic mustard in a plot and the number of other plant species.

READ MORE BORRELL ON DAVIS
ScientificAmerican.com/feb2011/more-borrell

Science cannot be motivated by ideology. It has to be driven by good data. I'm not against values at all, but when scientists express values, we need to make it clear that these are values we're expressing, as opposed to conclusions based on actual data. We've seen what's happened with climate change. As a scientific community, the worst thing we can do is to provide science skeptics more fuel for their arguments that scientists can't be trusted.

Aren't those who want to avoid the spread of nonnative species just being prudent?

The precautionary principle is used all the time, and it basically means, "Well, because we don't know, because of our ignorance as scientists, we have to act accordingly." The fact is, the world is changing in many ways. With climate change, some species are going to move to new areas, and there are going to be new combinations of species together in different conditions, different meteorological regimes. We can't predict the behavior of those species either. The future is unpredictable with native species and with nonnative species. Native species in the past that haven't been problematic might very well become problematic in the future. So the concern for future harm applies for all species, not just nonnatives.

You mean that native species can also be harmful to the environment?

Yes, of course. The best current example in North America may be the mountain pine beetle, a native insect in Western coniferous forests. This is a species that, probably partly because of a warming climate, has exploded in numbers in recent years and has been responsible for killing half the timber trees in some areas of British Columbia. No doubt about it—this is major economic harm.

But without natural enemies, a nonnative species has an advantage over natives. Haven't scientists documented their populations exploding exponentially after landing on new territory?

Nineteenth-century American botanist Asa Gray said that under the right conditions, any species could become a weed. Whether or not a species is able to become very abundant is going to depend on a combination of the traits of that particular species and the nature of the environment that it is established in.

Now, there have been many dozens of papers trying to determine whether there really are some predictable traits that distinguish species that are invasive versus noninvasive. For the most part, there hasn't been a lot of success.

One of the most important recent findings with respect to invasive plants is that the longer an invasive plant has been in an area, the greater the negative feedback becomes between itself and the soil environment. In other words, the number of pathogens in the soil that are able to infect it increases, resulting in a reduction in the abundance of the invasive plant. It's important for people to remember that just because a species comes in and becomes abundant, that doesn't mean it's going to remain abundant. In fact, if you believe in evolution, this is exactly what you would expect. Now, if the species is causing great economic or health harm, we can't wait around for the natural processes to take place and let the numbers begin to slide back down. We need to intervene.

The native prairie habitats where you work are also prime territory for biofuel production. In the hunt for the optimal biofuel crop, would you have a preference for a native over a nonnative?

In some respects, no, I don't have a preference, because concerns have been raised over even the native species that have been looked at, like switchgrass. For example, to get enough energy out of biofuel, the amount of land area that's going to have to be planted will need to be quite large and probably will require the planting of the grass outside of its current range. On the other hand, if we find a native species and there's enough of it, well, sure, I'd go with that first. My focus, and what I'm trying to argue, is that there should simply be less preoccupation with where a species is from and more of a focus on whether or not it really is a problem. I believe,

Nonnative species, such as the garlic mustard (*left*) and buckthorn shrub (*above*), appear everywhere on the planet. Invasive species only pose a problem, argues ecologist Mark Davis, when they create health threats or cause economic damage.

in time, historians of science will view this preoccupation with native versus nonnative as very much a 20th-century phenomenon.

Where did this fear of the nonnative originate? Is there a moment when humans first started realizing they were shaping the distribution of species?

We don't have documentation of it, but I'm sure that when humans were spreading from island to island in the South Pacific, they were aware they were transporting plants and animals with them, some of which would become naturalized in their new environment. Botanists during the Greek times were aware that travelers would sometimes bring back plants from other areas and would plant them. In 1850 we have explorer Alexander von Humboldt, who pointed out that the American prickly pear cactus *Opuntia* had been spreading throughout Europe, the Middle East and North Africa.

So when was there a shift from documenting these movements to thinking about preventing species from spreading and attempting to eradicate them?

Here in the U.S., our attitude toward nonnative—not just species but non-American things in general—has varied over the past several hundred years. When the country was younger, there was an interest in showing the world that we weren't just a frontier backwater. We could be cosmopolitan, too. We could be worldly. There was actually considerable interest in bringing in stuff, whether it was music or opera or art, as well as plants and animals, from other parts of the world. Some of those species that were brought in, for example, pest insects and weeds, turned out to cause problems, primarily by negatively affecting the country's agriculture. These observations gradually led to the shift in perspective at the federal level and efforts to control what species were brought in and to control those that were already here. With the advent of supposedly miracle chemical pesticides after World War II, such as DDT, the focus shifted from trying to just manage species to actually trying to eradicate them with DDT. We know how that turned out.

Has the pendulum begun to swing back in the other direction?

I think so. On the invasive species Web page of the Minnesota Department of Natural Resources is a statement emphasizing that most nonnative species are not problems. So the perspective and message are gradually becoming more nuanced now.

These days, more than ever, we need to spend society's fiscal resources wisely and strategically. The number of species that will be transported around the world is just going to increase. We need to focus our resources on those species that are truly causing serious harm. The others we need to learn to live with. SA

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

MORE TO EXPLORE

Out of Eden: An Odyssey of Ecological Invasion. Alan Burdick. Farrar, Straus and Giroux, 2005.
Invasion Biology. Mark A. Davis. Oxford University Press, 2009.
Rambunctious Garden: Saving Nature in a Post-Wild World. Emma Marris. Bloomsbury (in press).

Photographs by Amy Eckert

ASTROPHYSICS

X-RAY VISION

Thanks to amazing nested mirrors, NASA's NuSTAR telescope is set to reveal hidden phenomena in the cosmos

By Fiona Harrison and Charles J. Hailey

SOME OF THE UNIVERSE'S MOST EXTREME PHENOMENA—BLACK HOLES, NEUTRON STARS and remnants of stellar explosions—emit copious amounts of x-rays. Just as medical x-rays penetrate skin to reveal bone, cosmic versions pierce clouds of gas and dust to reveal hidden objects in our galaxy and beyond.

Until now, no NASA mission has been able to focus high-energy x-rays to make a clear, high-quality image. The Nuclear Spectroscopic Telescope Array (NuSTAR), to be launched in early 2012, will be the first. Made up of two mirrors, including the one at the right, plus a detector and an expandable mast, its pictures will be 100 times more sensitive than those of previous missions, with a resolution comparable to that of the human eye.

Building a camera to capture and record x-ray images is very different from designing one that records optical light. Visible light reflects off a mirror perpendicularly, which is why one holds a mirror parallel to one's face. X-rays, on the other hand, glance off a reflective surface at an angle nearly parallel to it, more like stones skipping off the surface of water. To gather this glancing radiation requires shells of glass, stacked much like plastic cups, one inside the other. Each shell, or layer, intercepts some of the incoming x-rays, and together they work to form a focused image.

Each of NuSTAR's optics is made up of 133 concentric shells of atomically smooth glass, so smooth that its bumps are no larger than the size of the spaces between its atoms. The glass—the same kind used in laptop and smart phone screens—has been coated with hundreds of alternating layers of metal and either carbon or silicon for reflectivity. Once the glass is prepared, a precision machine fixes each piece in place to a tolerance 20 times as thin as a human hair. Although the telescope may sound fragile, it has been built to withstand a turbulent takeoff onboard a rocket.

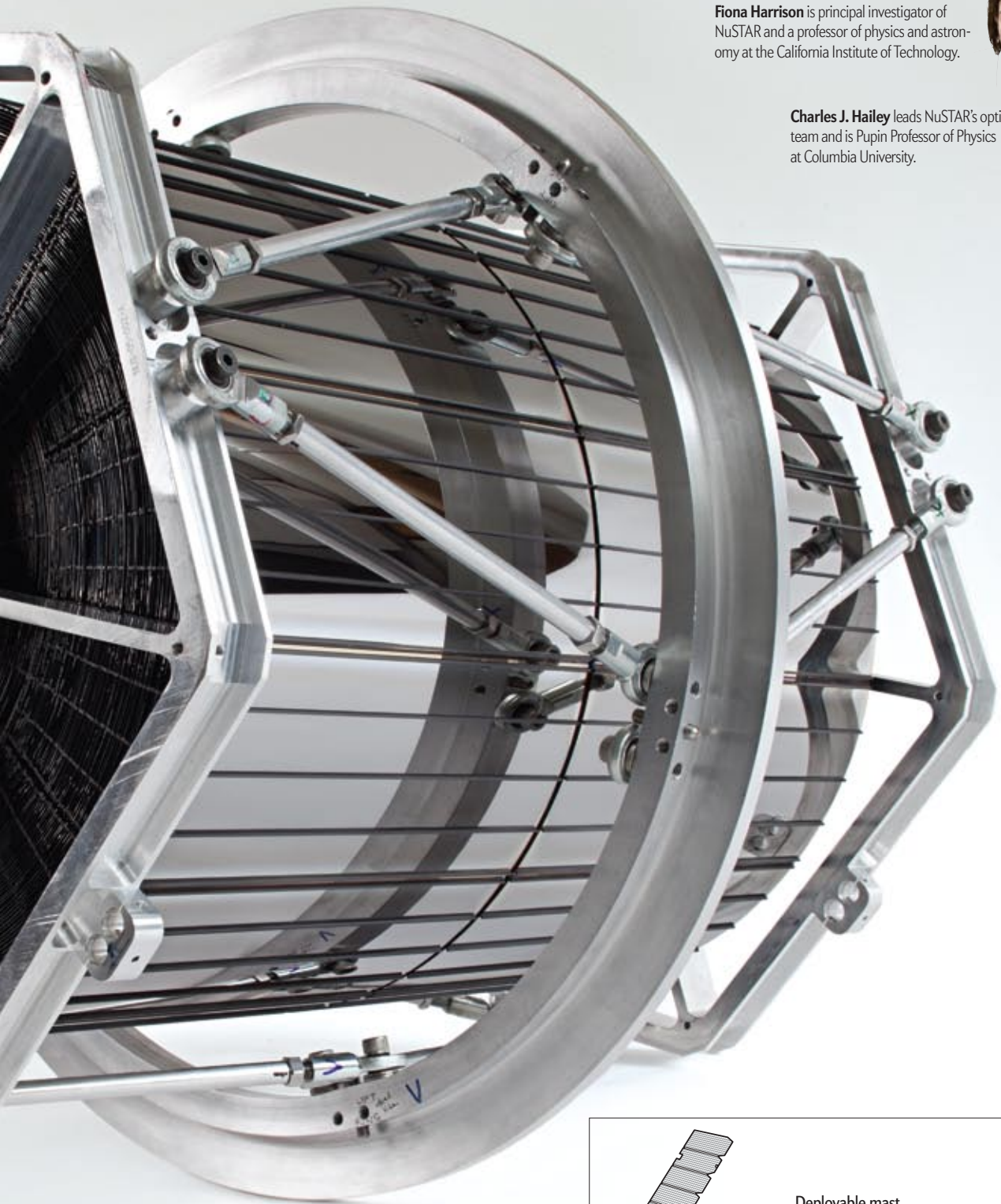
MORE PHOTOS OF NUSTAR
ScientificAmerican.com/feb2011/nustar

What will we find? Perhaps unusual objects that test physical models of celestial phenomena. Until now, astronomers have been poor predictors of the secrets the cosmos holds, but if history is a guide, surprising discoveries lie ahead. SA

Photograph by Floto + Warner

Fiona Harrison is principal investigator of NuSTAR and a professor of physics and astronomy at the California Institute of Technology.

Charles J. Hailey leads NuSTAR's optics team and is Pupin Professor of Physics at Columbia University.



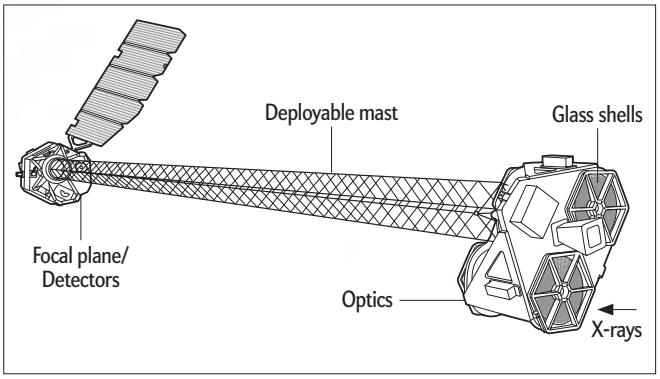


Illustration by Brown Bird Design

IN BRIEF

Signals channeled directly from the brain can already control computers and other machines.

Exoskeletons, full-body prosthetics, will ultimately connect directly to the brain as well.

Brain-wave control of external prosthetics and computers portends an Age of Machines in which we transfer thoughts as if they were mental telegrams.

Miguel A. L. Nicolelis has pioneered the field of neuroprosthetics. He is Anne W. Deane Professor of Neuroscience at Duke University and founder of Duke's Center for Neuroengineering.

NEUROPROSTHETICS

Mind Out of Body

In an exclusive excerpt from his new book, a pioneering neuroscientist argues that brain-wave control of machines will allow the paralyzed to walk and portends a future of mind melds and thought downloads

By Miguel A. L. Nicolelis

ALMOST EVERY TIME ONE OF MY SCIENTIFIC MANUSCRIPTS RETURNED from the mandatory peer-review process during the past three decades, I had to cope with the inevitable recommendation that all scraps of speculative thinking about our ability to interface brains and machines should be removed from the papers. More often than not, other neuroscientists who reviewed these papers before publication did not wish to entertain the notion that this research could lend support to more daring scientific dreams in the future. During those painful reckonings, I would fantasize about the day when I could rescue those speculative ideas and liberate them for others to consider and contemplate. Our progress in the laboratory means that the time to tell others has finally arrived.

While I have been confronting the ultraconservative culture of academia, a number of science-fiction writers and movie directors have been speculating unreservedly and at times overindulging in the excesses of their fertile imaginations. During 2009 alone, two Hollywood mega productions, *Surrogates* and *Avatar,* portrayed the stereotype of scientists controlling, harming, killing and conquering people with their technological wizardry. In these films, brain-machine interfaces allowed human beings to live, love and fight by proxy. Their full-body avatars were left to do the hard work of roaming the universe and, in some cases, seeking to annihilate an entire alien race on behalf of their human masters.

Let me present an alternative view on the coming Age of the Machines. After working and thinking long and hard about the impact of brain-wave-controlled robots, often called brain-machine interfaces, I see a future filled with blunt optimism and eager anticipation, rather than one plagued by gloom and calamity. Perhaps because so little about the true dimensions of this future can be conceived with certainty, I feel an intense calling to embrace the amazing opportunities that freeing our brains from the limits of our terrestrial bodies can bring to our species. In fact, I wonder how anyone could think otherwise, given the tremendous humanistic prospects that brain-machine interface research promises to unleash.

Through this "liberation" of the human brain from the physical constraints imposed by the body, the disabled may rise from wheelchairs. But there is more. An era of neurosocial networking looms. Forget texting and Twitter. In this brain-centered future, you may be able to communicate brain to brain directly to your co-worker in the next cubicle or to millions of followers in a new medium, which I call a brain net. Flickr will be ancient history. That mental image of the rosy dawn or your hometown team

Excerpt adapted from *Beyond Boundaries: The New Neuroscience of Connecting Brains with Machines—and How It Will Change Our Lives,* by Miguel Nicolelis. To be published March 15 by arrangement with Times Books, an imprint of Henry Holt and Company, LLC.

Illustration by Kenn Brown, Mondolithic Studios

winning the World Series will be relayed via radio-frequency brain waves directly to a pocket pentabyte drive.

WHICH ROBO SUIT SHOULD I WEAR?

YET CURRENT MUSINGS about downloading or simulating an entire brain into a computer will never come to pass. The essence of our personalities—what makes Nelson Mandela, say, such a special human being—will never transfer to a hard drive. But experiments in rodents, monkeys and humans have shown that brains can be directly linked to machines in a laboratory setting. Based on these findings, I foresee an exciting future.

In the next two decades brain-machine interfaces, built by connecting large chunks of our brains through a bidirectional link, may be able to restore humanity to those who have succumbed to devastating neurological diseases. The interfaces will likely begin to bring back neurological function to the millions of people who can no longer hear, see, touch, grasp, walk or talk by themselves. Those people may even achieve the unimaginable task of conversing through brain waves alone.

An international research consortium, the Walk Again Project, which I co-founded, offers a first glimpse of this future. Conceived a few years ago after my group demonstrated the feasibility of linking living brain tissue to a variety of artificial tools, the project aims to develop and implement the first brain-machine interface capable of restoring full-body mobility to patients suffering from severe body paralysis, whether it resulted from traumatic lesions of the spinal cord or from a neurodegenerative disorder.

To accomplish this goal, we are engineering a neuroprosthetic device that will allow paralyzed patients to use a brain-machine interface to control the movements of a full-body exoskeleton. This "wearable robot" will give the patients voluntary control over upper and lower limbs and will sustain and carry their bodies. We are basing this feat of neuroengineering on neurophysiological principles, derived empirically from our brain-machine-interface experiments with rhesus monkeys and many other animals.

In these experiments, a monkey named Aurora learned how to transmit through a brain-machine interface her thoughts of where a computer cursor should be positioned, a skill that became as natural and fluid as doing the same task with a joystick. We then performed the same experiment successfully in patients suffering from advanced Parkinson's disease. Still later, a monkey at my laboratory at Duke University learned how to transmit brain signals thousands of miles over the Internet to control the leg movements of a robot in Japan.

Now we have started going in the opposite direction, conveying direct signals into a monkey's cerebral cortex, letting the animal know that the "treat" of a food pellet resides in one box and not another. One of our next endeavors will allow one monkey to communicate the location of food to another. New-generation neuroprosthetics will require communication both to and from the outside world. The brain of the wearer will need to instruct a bionic foot, not only to ascend to the next step of a staircase but also to receive feedback that the prosthetic has actually contacted a hard surface before sending out a command to bring up the other foot.

With input-output links to the external world now in place, we will stand at the portals of a bionic future. Brain interfaces will merge with the most sophisticated robotic limbs now in testing. Robotic arms and legs will snap on like LEGO blocks to a biosynthetic torso. This robo suit, or exoskeleton, draped over the limp body of its wearer, will maintain a direct connection to the cerebral cortex, the brain's master command center.

Exoskeleton, a prosthetic that allows the disabled to walk, may one day be controlled by brain waves.

PAUL SAKUMA *AP Photo*

To realize the vision of a brain-machine-interface exoskeleton for the handicapped, we will need still more advanced technology. It will require a new generation of high-density microelectrodes that can be safely implanted in the human brain and provide reliable, long-term simultaneous recordings of the electrical activity of tens of thousands of neurons, distributed across multiple brain locations. Indeed, to make brain-machine interfaces medically practical and affordable, these large-scale recordings of brain activity will have to remain stable for at least a decade without any need for surgical repair.

Custom-designed neurochips also will be implanted permanently, which will allow us to condition and process the brain's electrical patterns into signals capable of controlling the exoskeleton. To reduce the risk of infection and damage to the cortex, these neurochips will have to incorporate low-power, multichannel wireless technology capable of transmitting the collective information generated by thousands of individual brain cells to a wearable processing unit, about the size of a modern cell phone. This unit will be responsible for running computational models of the brain's inner workings and designed to optimize immediate extraction of electrical brain signals that initiate movement.

The populations of neurons we sample to feed into this brain-machine interface will be distributed across multiple brain areas. Digital signals extracted from the raw electrical signals from the part of the brain that controls movement will prompt moving parts distributed across the joints of the robotic exoskeleton to budge. Neural signals will interact with the robo skeleton to mimic the functions of the human spinal cord. These commands will permit the patient to take one step and then another, slow down or speed up, bend over or climb a set of stairs. All the while, brain and machine will continue to send to and receive from each other in the background in a seamless dialogue. These techniques will create a continuous interplay between brain signals and robotic reflexes.

I also envision force and stretch sensors, distributed throughout the exoskeleton, that will generate a continuous stream of feedback signals for artificial touch and proprioception (sensing of the suit's positioning) to update the patient's brain. Electrical microstimulators will deliver signals to the cortex. Alternatively, optical signals will activate light-sensitive ion channels deployed directly into the patient's cortex. Based on our prior lab experiments with brain-machine interfaces in monkeys, I expect that after a few weeks of interaction, the patient's brain will completely incorporate the entire exoskeleton as a true extension of the person's body image. At that point, the patient will be able to use the brain-interface-controlled exoskeleton to move freely and autonomously around the world.

THE PROSPECT OF NEURAL APPS

WHAT COULD HAPPEN within a few decades if we master technologies that allow humans to utilize the electrical activity of their brains to interact with all kinds of computational devices? From tiny personal computers that we carry with—or possibly within—us to remote distributed networks aimed at mediating our digital social interactions, our daily lives will look and feel much different from what we are accustomed to today.

For starters, interacting with the operating system and software of one's personal computer will likely become an embodied adventure, as our brain activity is used to grab virtual objects, trigger programs, write memos and, above all, communicate freely with other members of our favorite brain net, a considerably upgraded version of online social networking. The fact that Intel, Google and Microsoft have already created their own brain-machine divisions shows that this idea is not far-fetched. The main obstacle: development of a noninvasive method to sample the brain activity needed to make such brain-machine interfaces a reality. I feel confident that a solution will be found in the next 20 years.

At that time, what may sound unimaginable will become routine, as augmented humans make their presence felt in a variety of remote environments, through avatars and artificial tools controlled by thought alone. From the depths of the oceans to the confines of supernovae, even to the tiny cracks of intracellular space inside our own bodies, the human reach will finally catch up to our species' voracious ambitions to explore the unknown. It is in this context that I envision our brains will eventually complete their epic journey from the obsolete terrestrial bodies they have inhabited for millions of years and, through the use of bidirectional, thought-driven interfaces, operate a myriad of nanotools that will serve as our new eyes, ears and hands in the many tiny worlds crafted by nature.

WATCH A VIDEO OF MIND CONTROL
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On the scale of the very large, we will likely be able to operate remotely controlled envoys and ambassadors, robots and airships of many shapes and sizes, sent on our behalf to explore other planets and stars in distant corners of the universe and capable of placing strange lands and scenery at our mental fingertips.

With each step in our explorations, we will continue to assimilate the tools created by our descendants for these mind voyages as further extensions of the self, defining a view of the world and a way of interacting with it that goes far beyond anything we can imagine today. This thought brings me an enormous feeling of elation and awe, which resembles the profound emotion that a Portuguese sailor, 500 years ago, may have experienced when, at the end of a long and life-threatening journey, he found himself staring at the bright, sandy shores of a new world.

Could such a complete liberation of the brain allow us to blur, or even eliminate, the once inexpugnable physical borders that define an individual human being? Could we one day, in a remote future, experience what it is to be part of a conscious network of brains, a collectively thinking true brain net? Assuming this brain net became real, could the individual participants not only communicate back and forth with one another just by thinking but also vividly experience what their counterparts feel and perceive, as they seamlessly adhere to this true "mind meld"? Very few people today would likely choose to venture into these unknown waters, but it is impossible to know how coming generations will react if presented with the opportunity to experience such a literally mind-boggling experience.

Accepting that all these stunning scenarios could actually take place and taking for granted that such a collective mind meld could become consensually accepted as an ethical way through which future generations interact and share their humanity, could these descendants of ours wake up one morning and simply realize that they had peacefully given birth to a different human species altogether? It is not inconceivable that our progeny may indeed muster the skills, technology and ethics needed to establish a functional brain net, a medium through which billions of human beings consensually establish temporary direct contacts with fellow humans through thought alone.

What such a colossus of collective consciousness may look like or feel like, neither I nor anyone in our present time can possibly conceptualize. It may, without our expecting it, proffer the ultimate human perceptual experience: to discover that each of us is not alone, that our most intimate thoughts, experiences, anguish, passions and desires, the very primordial stuff that defines us as humans, can be shared by billions of our brothers and sisters.

It takes just a minor leap of imagination to think that, in the midst of their newly acquired wisdom, our progeny may also decide to cross yet another Rubicon in our species' epic history and strive to document, for the benefit of future generations and the posterity of the cosmos, the richness and diversity of their human inheritance. Such an inestimable treasure could only be assembled, I suggest, by preserving the irreplaceable, first-person narrative of each and every single human lifetime story by transferring our memories to a digital storage medium. This action would serve to protect the unique account of our mortal existence that, after a brief temporary stay in one's mind, is irremediably lost at the end of our lives, in a rare wasteful lapse of nature.

Before my own career is over, I hope that endeavoring to dream big will help realize this vision—a trajectory that envisages a pathway from today's brain control of computers to eventual exoskeletons to perhaps even neurotexting. It would be an amusing coda to my time in the trenches of science to finally answer a querulous academic reviewer by seeding his auditory cortex with just the kind of reply I have been meaning to convey for decades. SA

MORE TO EXPLORE

Controlling Robots with the Mind. Miguel A. L. Nicolelis and John K. Chapin in *Scientific American*, Vol. 287, No. 4, pages 46–53; October 2002.

Seeking the Neural Code. Miguel A. L. Nicolelis and Sidarta Ribeiro in *Scientific American*, Vol. 295, No. 6, pages 70–77; December 2006.

Lee Dugatkin has authored more than 125 research publications on the evolution of social behavior, which he studies at the University of Louisville. On February 12, Dugatkin will lecture on "Jefferson and the French: Dispelling Misconceptions" at a Lewis and Clark symposium at the Smithsonian Institution.

HISTORY OF SCIENCE

Jefferson's Moose

Thomas Jefferson waged a second revolution, fighting the image created by European naturalists of a degenerate America

By Lee Dugatkin

THOMAS JEFFERSON IS BEST KNOWN FOR EXPRESSING IN WORDS THE JUSTIFICATION FOR American independence. But Jefferson the politician and statesman coexisted with Jefferson the scientist. The combination led Jefferson to invest a great amount of time and energy in debunking a popular European conceit—that America was a degenerate place. American degeneracy allegedly was evident in its weak and stunted flora, fauna and people.

Jefferson's effort to illustrate the complete biological equality of the New and Old Worlds went beyond mere pride in his home continent—he and other founders believed that a successful rebuttal was necessary to ensure the growth and prosperity of their new country. The fight was important enough to have been noted in a eulogy at Jefferson's funeral in 1826 by New York Senator Samuel Latham Mitchill, who called the antidegeneracy campaign the equivalent of proclaiming independence a second time. And one piece of concrete evidence that Jefferson thought he needed to win the day was a specimen of an American moose.

BUFFON'S CLAIMS OF DEGENERACY

THE EUROPEAN BELIEF IN AMERICAN INFERIORITY originated to a great extent with the most influential natural historian of the 18th century. Georges-Louis Leclerc—known as Count Buffon—was arguably the most famous scientist of his day. He wrote the 36-volume *Natural History,* still regarded as a masterpiece. His goal was to provide "the exact description and the true history of each thing" on earth. *Natural History* was a huge success, became the talk of the salons of Paris and

IN BRIEF

European naturalists led by Count Buffon developed a theory of American biological degeneracy during the Revolutionary War era.

Thomas Jefferson attacked the theory, fearing that it could impede the economic and cultural maturation of the fledgling U.S.

A large moose was a key piece of evidence that Jefferson hoped to present to Buffon to get him to recant the degeneracy theory.

Photograph by Richard Ross

Jefferson saw the moose, *Alces alces*, as incontrovertible evidence against the European idea that American fauna was somehow small and weak.

was translated into English, German and Dutch.

In volumes 9 and 14 of *Natural History,* Buffon argued that most animals—and people—in the Americas were lesser than in the Old World. The echoes of that conceit still reverberate. In his 2005 book *The American Enemy: The History of French Anti-Americanism,* Philippe Roger argues that the French attitude "was born and proposed in philosophical circles" that revolved around Buffon.

The explanation: colder and more humid conditions had somehow brought about this state. The exceptions: Buffon was willing to cede that frogs—which were said to weigh up to 37 pounds—and insects were larger in America. But these examples only reinforced the degeneracy rule, as what could be more repugnant than a massive frog or mosquito?

Count Buffon

Buffon laid out four related claims. Animals found in *both* hemispheres were smaller and feebler in the New World. Animals that lived only in the New World were somehow lesser than comparative species found only in the Old World. The New World had fewer species. And, finally, the New World actually caused degeneration in livestock.

Readers of *Natural History* were told that sheep raised in the New World were "commonly more meagre, and their flesh less juicy and tender than those of Europe." They learned that the New World had but half the species of the Old and that they were a motley lot. Buffon even claimed that most American birds could not sing, a falsehood based on a line in a 1769 Oliver Goldsmith poem, "The Deserted Village," about the Georgia wilderness: "Those matted woods, where birds forget to sing."

After dispensing with the animals, Buffon moved to the indigenous peoples. American Indians had "no vivacity, no activity of mind." They were, Buffon claimed, "a kind of weak automaton, incapable of improving or seconding [Nature's] intentions." Thus were Native Americans *responsible* for the poor show of the rest of the New World's occupants. Having failed to tame nature, the natives had neglected to produce an environment conducive to forming healthier specimens of fauna, he explained.

Buffon never left Europe. He relied on natural history publications and the accounts of visitors. It was standard practice for such business travelers and missionaries to take notes on the animals they encountered, particularly previously unknown species. The count would compare the notes of travelers and distill them into a general description. This system had obvious faults, as Buffon himself admitted—there were tall tales in the mix. For example, one Peter Kalm, sent by the Swedish Academy to study the natural history of America, alleged to have seen a bear kill a cow by biting into its hide and then blowing into the puncture wound until the cow virtually exploded and expired. Compared with these fictions, less extreme accounts could be easy to accept, and Buffon used many less extreme briefings as prima facie evidence of degeneracy in *Natural History.*

DUGATKIN PODCAST INTERVIEW
ScientificAmerican.com/feb2011/podcast

BUFFON'S INFLUENCE

INTELLECTUAL DESCENDANTS OF BUFFON—such as the Prussian Abbé Cornelius de Pauw and the French Abbé Guillaume-Thomas Raynal—saw degeneration in the New World as all encompassing. The only flaw they found in Buffon was that he had not gone far enough. They extended the case to all Americans, including transplanted Europeans and their descendants. De Pauw, unrestricted by fact, claimed that American dogs were "perfectly mute." As a confidant to Frederick the Great, who did not want Prussians leaving for opportunities in the New World, De Pauw most likely had personal motives for such propaganda.

Raynal, a more respected and complex character than de Pauw, wrote in his eight-volume *A Philosophical and Political History of the Settlements and Trade of the Europeans in the East and West Indies*, "One should not be surprised that America has yet to produce a good poet, a clever mathematician, a genius in even one art or science." But Raynal had the capacity to revise his opinion, which he did after dining with Benjamin Franklin and several other Frenchmen and Americans in the late 1760s.

Franklin, of course, was a world-class scientist whose 1752 Royal Society publication about his lightning experiment was an instant classic. He devised an impromptu test of the effects of the New World. Jefferson told the story in a letter after hearing it from Franklin. "[Raynal] got on his favorite theory of the degeneracy of animals, and even of man, in America," Jefferson wrote. Franklin noticed that the Americans were on one side of the table and the Frenchmen were on the other. "Let both parties rise," Franklin said, "and we will see on which side nature has degenerated." The Americans were bigger to a man, with the Abbé himself, in Jefferson's own words, "a mere shrimp." (One of the other Americans present said that any of them could have easily tossed one, or even two, of the Frenchmen out of the window.)

Raynal nonetheless published the slanderous first edition of *A Philosophical and Political History.* By the third edition, however, he had renounced his previous views. Unfortunately, the ideas were already well established in the European mind.

JEFFERSON COUNTERS THE COUNT

THE FOUNDING FATHERS were all too familiar with Buffon. It was one thing for Europeans, particularly the French, to refer to Americans as upstarts, malcontents and threats to monarchy—they were. It was another matter entirely to say that all life-forms in America, including its aboriginal population and its European immigrants, were degenerate.

Jefferson, the biggest Francophile of the founders, took it upon himself to refute Buffon and his supporters. Indeed, this effort became something of an obsession for the passionate naturalist, who once wrote to his daughter Martha, "There is not a sprig of grass that shoots uninteresting to me."

Jefferson attacked Buffon with an overwhelming collection of facts. In his *Notes on the State of Virginia,* written when he was governor, Jefferson devoted the longest chapter to a point-by-point dismantling of the theory of degeneracy. He included tables of data, comparing measured sizes of animals, that disproved the count's notions. He argued that the count's ideas were conceptually unsound and that the data he was getting from travelers were inaccurate.

What proof existed, Jefferson asked, that the environments of the Old and New Worlds were so different? "As if both sides were not warmed by the same genial sun; as if a soil of the same chem-

LEONARD DE SELVA *Corbis*

ical composition was less capable of elaboration into animal nutriment; as if the fruits and grains from that soil and sun … gave less extension to the solids and fluids of the body, or produced sooner in the cartilages, membranes, and fibres, that rigidity which restrains all further extension, and terminates animal growth." The truth, Jefferson wrote, "is that a Pygmy and a Patagonian, a Mouse and a Mammoth, derive their dimensions from the same nutritive juices."

Thomas Jefferson

Jefferson was not the only founder to jump into the fray. John Adams called de Pauw's ideas "despicable dreams." In addition to his dinner demonstration, Franklin disputed the humidity argument. A world traveler and conscientious data collector, he pointed out in 1780 that the humidity, a supposed cause of degeneracy, was actually higher in Europe than in the colonies.

Alexander Hamilton, especially fearful of the degeneracy theory's potential to stifle trade relations, defended America in the *Federalist Papers:* the only footnote in Federalist No. 11 is a rebuttal to de Pauw's absurd assertion of nonbarking dogs.

And Jefferson's eventual successor as president, James Madison, even served as a research assistant. He concludes a June 1786 letter to Jefferson with a discussion of weasels, complete with measurements: the American species was as large as its European equivalent. Madison wrote to his mentor that the finding "certainly contradicts [Buffon's] assertion that of the animals common to the two continents, those of the new are in every instance smaller than those of the old." In the midst of discussing such issues as a constitutional convention and the new country's treasury requirements, both men clearly thought that battling Buffon was of national import.

THE ANSWER OF *ALCES ALCES*

JEFFERSON BELIEVED that the methodical dismantling of degeneracy in *Notes on the State of Virginia* would go only so far in his quest to make people reject the unsupported ideas. He wanted to convince Buffon himself to publicly recant his theory. And so, before Jefferson set off for France to serve as ambassador, he was determined to present Buffon with an American animal so impressive as to impel the French luminary to change his opinion. Enter *Alces alces:* the moose.

Jefferson began his quest for a large moose by sending out a 16-question survey to his friends on the habits, size and natural history of the moose. And he made it clear that if hunters could procure for him the skeleton of a giant moose, he would be deeply indebted. Revolutionary War general and New Hampshire governor John Sullivan responded enthusiastically and was on the case when Jefferson left the U.S.

After arriving in France, Jefferson wrangled an invitation to meet Buffon. They had far-ranging conversations that included, of course, the theory of degeneracy. Minister Jefferson told the count that the European "reindeer could walk under the belly of our moose." Jefferson left the meeting with the impression that the count would "give up the question" of degeneracy if he could but see a massive moose.

Finally, in the winter of 1786–1787, Jefferson received good news: Sullivan had procured the remains of a moose from a Captain Colburn, who had killed a seven-foot-high specimen in Vermont. It took 14 days for a team of men to deliver the moose to Sullivan's home. Sullivan then hired a ship's captain to take the moose with him on his next trip overseas.

All was going along according to plan, but the moose was inexplicably left on the dock when the ship set sail. Sullivan sent the bad news. Distraught, Jefferson believed his quest for the evidentiary moose had led to naught. He wrote to a friend that "the box, bones and all are lost; so that this chapter of natural history will still remain a blank." What Jefferson did not yet know was that Sullivan had recouped the moose and hired another ship. The specimen arrived in Paris around October 1, 1787.

Jefferson was ecstatic. He wanted to take the moose to Buffon personally, but the count was ill and not receiving visitors. So he sent the moose to Buffon's assistant. Buffon apparently saw the moose, because Jefferson wrote that the giant creature had "convinced Mr. Buffon. He promised in his next volume to set these things right." But six months later Buffon was dead, and no revisions to his theory were published. The influential *Natural History* would forever promote the theory of a degenerate New World.

DEGENERACY'S DISAPPEARANCE AND LEGACY

THE IDEA OF AMERICAN DEGENERACY evolved with modification for at least another six decades before withering and leaving only a dried husk of general anti-Americanism. Two factions formed. Philosopher Immanuel Kant and poet John Keats accepted degeneracy wholesale. Keats described America as the single place where "great unerring Nature once seems wrong." Kant, displaying a lack of pure reason, wrote of de Pauw that "even if nine-tenths of his material is unsupported or incorrect, the very effort of intelligence deserves praise and emulation, as making one think and not simply read thoughts."

On the other side, Jefferson's troops included writers Lord Byron, Washington Irving and Henry David Thoreau and geographer Jedidiah Morse (father of telegraph inventor Samuel). Byron called America "one great clime." Irving skewered Buffon's theory in *The Sketchbook of Geoffrey Crayon,* writing that he "will visit this land of wonders [Europe] … and see the gigantic race from which I am degenerated." Thoreau used his *Walking* as a platform "to set against Buffon's account of this part of the world and its productions." And Morse debunked degeneracy in the opening 10 pages of the geography textbook that the first generation of U.S. children would read in their schoolhouses.

These American writers, responding to the idea of New World inferiority, forged a counternarrative of America as a beautiful, vast, resource-rich region filled with robust individualists. The American identity to this day—and the rest of the world's reactions to that modern self-image—can thus be partly traced back to the vigorous debunking, by Jefferson, his peers and his followers, of the accusation of American biological degeneracy. SA

MORE TO EXPLORE

The American Enemy: The History of French Anti-Americanism. Philippe Roger. University of Chicago Press, 2005.

Mr. Jefferson and the Giant Moose: Natural History in Early America. Lee Alan Dugatkin. University of Chicago Press, 2009.

JAMES SHARPLES Getty Images

The Artist and the Scientists: Bringing Prehistory to Life

by Peter Trusler, Patricia Vickers-Rich and Thomas H. Rich. Cambridge University Press, 2010 ($48)

Artist Peter Trusler and paleontologists Patricia Vickers-Rich and Thomas H. Rich team up to explain the process of reconstructing scenes of prehistoric life from fossils of long-gone beasts.

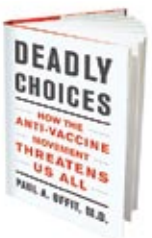
Ancient amphibian *Koolasuchus cleelandi*

EXCERPT

Deadly Choices: How the Anti-Vaccine Movement Threatens Us All

by Paul A. Offit. Basic Books, 2011 ($27.50)

Paul A. Offit, *chief of the division of infectious diseases at Children's Hospital of Philadelphia and a professor of pediatrics at the University of Pennsylvania School of Medicine, explores why many parents fear that vaccines will cause autism and other disorders and are therefore forgoing vaccination in increasing numbers. Here he traces the birth of the antivaccine movement to a 1982 documentary produced by NBC television correspondent Lea Thompson called* DPT: Vaccine Roulette. *It linked the diphtheria-tetanus-pertussis (DTP, sometimes also called DPT) vaccine to brain damage, laying the groundwork for the autism scare.*



"*Vaccine Roulette* was arguably one of the most powerful programs ever to air on American television: thousands of parents stopped giving pertussis vaccine to their children; personal-injury lawyers pummeled pharmaceutical companies, causing many to stop making vaccines; and Congress passed a law to protect vaccine makers, while at the same time compensating those who were allegedly harmed by vaccines.

"During the next fifteen years the tide turned … study after study showed that children immunized with DTP weren't at greater risk of brain damage. As a consequence, public health agencies and medical societies throughout the world no longer considered pertussis vaccine to be a rare cause of permanent harm.…

"Despite this overwhelming evidence, and despite all the harm that had been done by the false notion that pertussis vaccine was maiming America's children, Lea Thompson was without remorse. In 1997, during a celebration in her honor … Thompson remembered *Vaccine Roulette:* 'The reason it was important to me is not because it was great research, although we did a pretty good job, or that [it] was a beautifully produced piece of work. *DPT* [*Vaccine Roulette*] was important to me personally because it spawned a movement.' A movement that almost eliminated vaccines for American children, a movement that continues to cause many parents to reject vaccines in favor of the diseases they prevent, and a movement that was based on a notion that has been shown again and again to be incorrect."

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ALSO NOTABLE

NONFICTION

The 4% Universe: Dark Matter, Dark Energy and the Race to Discover the Rest of Reality, by Richard Panek. Houghton Mifflin Harcourt, 2011 ($26)

Why Everyone (Else) Is a Hypocrite: Evolution and the Modular Mind, by Robert Kurzban. Princeton University Press, 2011 ($27.95)

World Wide Mind: The Coming Integration of Humans and Machines, by Michael Chorost. Free Press, 2011 ($26)

The Clockwork Universe: Isaac Newton, the Royal Society, and the Birth of the Modern World, by Edward Dolnick. HarperCollins, 2011 ($27.99)

The Belief Instinct: The Psychology of Souls, Destiny, and the Meaning of Life, by Jesse Bering. W. W. Norton, 2011 ($26.95)

DNA: A Graphic Guide to the Molecule That Shook the World, by Israel Rosenfield, Edward Ziff and Borin Van Loon. Columbia University Press, 2011 ($19.95)

Quirk: Brain Science Makes Sense of Your Peculiar Personality, by Hannah Holmes. Random House, 2011 ($26)

The Philosophical Breakfast Club: Four Remarkable Friends Who Transformed Science and Changed the World, by Laura J. Snyder. Broadway, 2011 ($27)

Ah-choo!: The Uncommon Life of Your Common Cold, by Jennifer Ackerman. Twelve, 2010 ($22.99)

FICTION

The Omega Theory, by Mark Alpert. Touchstone, 2011 ($24.99)

The Dinosaur Hunter, by Homer Hickam. Thomas Dunne Books, 2010 ($25.99)

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

Houdini's Skeptical Advice

Before you say something is out of this world, first make sure that it is not in this world

Sir Arthur Conan Doyle was the brilliant author of the wildly popular Sherlock Holmes detective stories, which celebrated the triumph of reason and logic over superstition and magical thinking. Unfortunately, the Scottish physician-turned-writer did not apply his creation's cognitive skills when it came to the blossoming spiritualism movement of the early 1900s: he fell blindly for the crude hoax of the Cottingley Fairies photographs and regularly attended séances to make contact with family members who had died in the First World War, especially his son Kingsley. Perhaps fittingly, Conan Doyle's fame brought him into company with the greatest magician of his age, Harry Houdini, who did not suffer fakes gladly.

In the spring of 1922 Conan Doyle visited Houdini in his New York City home, whereupon the magician set out to demonstrate that slate writing—a favorite method among mediums for receiving messages from the dead, who allegedly moved a piece of chalk across a slate—could be done by perfectly prosaic means. Houdini had Conan Doyle hang a slate from anywhere in the room so that it was free to swing in space. He presented the author with four cork balls, asking him to pick one and cut it open to prove that it had not been altered. He then had Conan Doyle pick another ball and dip it into a well of white ink. While it was soaking, Houdini asked his visitor to go down the street in any direction, take out a piece of paper and pencil, write a question or a sentence, put it back in his pocket and return to the house. Conan Doyle complied, scribbling, "*Mene, mene, tekel, upharsin,*" a riddle from the Bible's book of Daniel, meaning, "It has been counted and counted, weighed and divided."

How appropriate, for what happened next defied explanation, at least in Conan Doyle's mind. Houdini had him scoop up the ink-soaked ball in a spoon and place it against the slate, where it momentarily stuck before slowly rolling across the face, spelling out "M," "e," "n," "e," and so forth until the entire phrase was completed, at which point the ball dropped to the ground. According to William Kalush and Larry Sloman in their 2006 biography *The Secret Life of Houdini* (Atria Books), the Master Mystifier then dealt Conan Doyle the lesson that he—and by implication anyone impressed by such mysteries—needed to hear:

> *Sir Arthur, I have devoted a lot of time and thought to this illusion … I won't tell you how it was done, but I can assure you it was pure trickery. I did it by perfectly normal means. I devised it to show you what can be done along these lines. Now, I beg of you, Sir Arthur, do not jump to the conclusion that certain things you see are necessarily "supernatural," or the work of "spirits," just because you cannot explain them….*

Lamentably, Sir Arthur continued to believe that Houdini had psychic powers and spiritual connections that he employed in his famous escapes.

This problem is called the argument from ignorance ("it must be true because it has not been proven false") or sometimes the argument from personal incredulity ("because I cannot imagine a natural explanation, there cannot be one"). Such fallacious reasoning comes up so often in my encounters with believers that I conclude it must be a product of a brain unsatisfied with doubt; as nature abhors a vacuum, so, too, does the brain abhor no explanation. It therefore fills in one, no matter how unlikely. Thus do normal anomalies become paranormal, natural phenomena become supernatural, unidentified flying objects become extraterrestrial spacecraft and chance events become conspiracies.

Houdini's principle states that just because something is unexplained does not mean that it is paranormal, supernatural, extraterrestrial or conspiratorial. Before you say something is out of this world, first make sure that it is not in this world, for science is grounded in naturalism, not supernaturalism, paranormalism or any other unnecessarily complicated explanations. SA

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Illustration by Pat Kinsella

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.

La Bummer

In some cases, science and art really can't get along

Once a year I treat myself to a night at the opera. Not the Marx Brothers movie—I own a copy and watch it more than once a year. No, I mean an evening at the actual Metropolitan Opera, which is pretty much the most spectacular entertainment opportunity in New York City once the baseball season is over. Of course, my rare trips to both the Met and Yankee Stadium bring to mind the kangaroo in the saloon who responds to the bartender's comment about not getting a lot of marsupial customers with, "Not at these prices."

That old warhorse *La Bohème* was the opera I wound up at in early December. For anyone unfamiliar with the plot, it's the story of Rodolfo and his deadbeat Parisian buddies who labor under the misapprehension that they are great poets and painters when in fact they are all world-class singers.

There is a lot of eating, drinking, flirting and general bourgie behavior, all of which would be only mildly tragic if not for the metaphorical elephant in the room. (The actual elephant is in *Aida*.) Because as soon as the character Mimì walks onstage, she coughs. And somebody who coughs in a theatrical production might as well be wearing a red shirt in a *Star Trek* landing party. For you see, as *The Odd Couple*'s Felix Unger succinctly captioned card number 16 in the "Great Moments in Opera" bubblegum card collection he created for kids who don't like sports, "Mimì Gets Tuberculosis."

As Mimì's disintegrating lungs somehow still belted at jet-engine decibel levels, I thought about how the incredible advances in science and technology over the past century would negatively affect *La Bohème*'s story line. (The result would certainly not be the musical *Rent*. That show was so mid-1990s. None of those antediluvian people even had Facebook pages or Twitter accounts.)

In my version, today's Rudy is a hipster taken to wearing a vintage trilby hat ironically. He lives in a studio apartment off Bedford Avenue in Brooklyn. He might consider heating the room by burning the pages of the bad play he has been writing, except that it exists only inside his MacBook, albeit a three-year-old secondhand computer with only a 2.0-GHz processor rather than the 2.4-GHz processor on the newer models.

Downstairs neighbor Mimsy—she changed her name from Mimì after reading Lewis Carroll's "Jabberwocky" in the fifth grade—is not an embroiderer but rather a freelance Web site designer. She shows up at Rudy's not because her candle has gone out but because she wants to borrow a 23-watt compact fluorescent lightbulb (100-watt incandescent equivalent).

Mimsy clears her throat forcefully. Rudy asks if she's okay. She says, "Believe it or not, I had TB. Picked it up volunteering at a homeless shelter. But I was treated by health care practitioners from the New York City Department of Health and Mental Hygiene's Bureau of Tuberculosis Control. They have a really effective Directly Observed Therapy treatment regimen. They gave me anti-TB meds and showed up here two or three times a week to actually watch me take the drugs. It's incredibly effective as long as you don't have a multidrug-resistant strain, which I didn't. Anyway, I'm fine."

"Cool," Rudy responds. He knows he has no lightbulbs of any kind but tells Mimsy he'll look because he wants to figure out a way to keep her around—if only to check out the Android smart phone she's holding. Mimsy finds Rudy somewhat attractive despite the hat, so while he makes a show of investigating the contents of various cabinets, she Googles him.

"What do you do again?" she asks. "I'm a writer," he says while rifling through a kitchen drawer. "Cool," she says. The Google search turns up no publications.

"Sorry, no dice on the light," he says. "Thanks, anyway," she says. "Hey, you wanna cuppa coffee or anything?" is the best he comes up with. "Maybe if you publish something, loser," she thinks. "I actually have to run," says Mimsy. "Cool, maybe another time," says Rudy. "Sure," Mimsy says as she exits the apartment. Rudy lights up his 34th Natural American Spirit cigarette of the day. He takes a drag. He coughs. SA

COMMENT ON THIS ARTICLE ONLINE
ScientificAmerican.com/feb2011

Illustration by Matt Collins

February 1961

Protein Structure

"Only when the structures of large numbers of proteins have been worked out will biochemists be in a position to answer many of the fundamental questions they have long been asking. It is well to point out that the chemical approach does not provide a complete solution to the problem of protein structure. The order of links in the chain is not the whole story. Each chain is coiled and folded in a three-dimensional pattern, no less important than the atom-by-atom sequence in determining its biological activity. Chemical methods can provide only a partial insight into this three-dimensional, or 'tertiary' structure. In the past few years the spatial problem has begun to yield to x-ray analysis. —William H. Stein and Stanford Moore"

Stein and Moore were awarded a share of the 1972 Nobel Prize in Chemistry for their work on the complex protein ribonuclease.

Fail Safe

"'Radar reflections from the moon set off a missile scare at the nation's air defense centers on October 5,' the Associated Press reported. 'The incident … occurred when computers at the Ballistic Missile Early Warning Station at Thule, Greenland, picked up radar signals it had bounced off the moon, 250,000 miles away.' According to the Air Force, the dispatch continued, 'the scare was only momentary, since a quick check turned up the error.… The Air Force said that its equipment had been adjusted to avert more such flurries.'"

Science on the farm: New types of machines and motive power boost agricultural yield, 1911

February 1911

Inventors and Farmers

"In all the history of empire building there is no chapter to compare with that which tells the story of the development of the great West from a vast stretch of prairie, desert and primeval forest into the richest and most extensive agricultural empire in the world. The rapidity and completeness with which this transformation has been effected are chiefly due to the invention of agricultural machinery of wonderful precision and capacity [*see illustration*]. The mechanical engineer has at once simplified work and increased output from the farm."

Rats and People

"In 1905 the Plague Research Commission was appointed to investigate the plague in India, and early turned its attention to the relationship of rat plague and human plague. Every outbreak of bubonic plague, when adequately investigated, was found to be associated with the disease among rats—the rat epizootic preceding the epidemic by an interval of ten to fourteen days. In Bombay the rat population is an enormous one. *Mus decumanus* (the brown or gray rat) swarming in the sewers, gullies and outhouses in the city, and *Mus rattus* (the black rat) living in countless numbers in the houses of the people—it may almost be said to be a domesticated animal."

Read the article in full at www.ScientificAmerican.com/feb2011

February 1861

Pyrethrin Insecticides

"A vegetable powder, under the name of 'Persian Insect Powder,' has lately been introduced into the drug market, for the extermination of insects, vegetable parasites, &c. Until recently, the botanical source of this powder has not been known, except to its maker. For a number of years it was erroneously considered to be a native of Persia, but it has been traced beyond question by Dr. Koch, as having its origin in the Caucasian provinces, and to the contused blossoms and flowers of *Pyrethrum roseum* and *Pyrethrum carneum*. It is of a yellowish, gray color, perfectly odorless, yet slightly irritating to the nostrils; at first almost tasteless, but afterwards leaving a burning sensation upon the tongue. As its effects for the destruction of bugs, roaches, parasites on delicate plants, &c. have been fully established, and it being otherwise harmless, its introduction into general use would be of great importance to families and horticulturists."

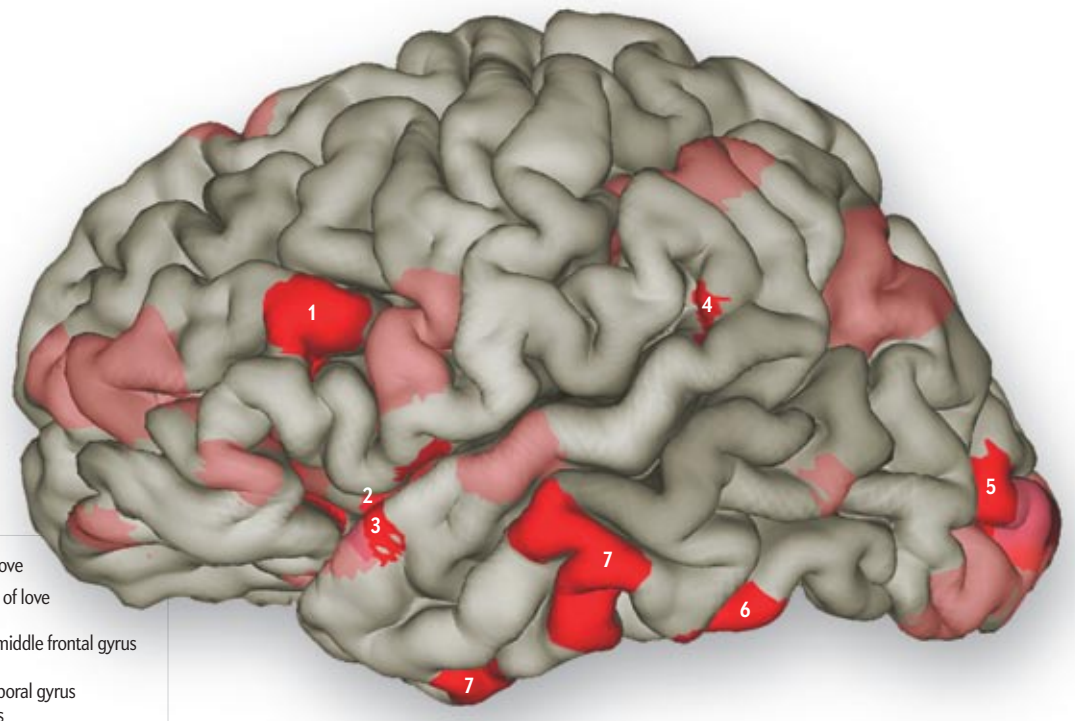
Safe Fail

"The safe-key of the Revere Bank, Boston, with a million combinations, became disarranged recently, and the mechanical skill of the maker could not open it. Business was at a standstill. A gang of workmen were at last set to work to batter down the masonry." SA

SCIENTIFIC AMERICAN, VOL. CIV, NO. 7; FEBRUARY 18, 1911

Your Brain in Love

Cupid's arrows, laced with neurotransmitters, find their marks



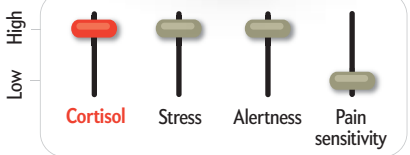
Active regions

- Passionate love
- Other types of love

1. Dorsolateral middle frontal gyrus
2. Insula
3. Superior temporal gyrus
4. Angular gyrus
5. Occipital cortex
6. Occipitotemporal cortex
7. Ventral temporal regions

Interior passion regions not visible: Caudate nucleus, thalamus, anterior cingulate, posterior hippocampus, precentral gyrus

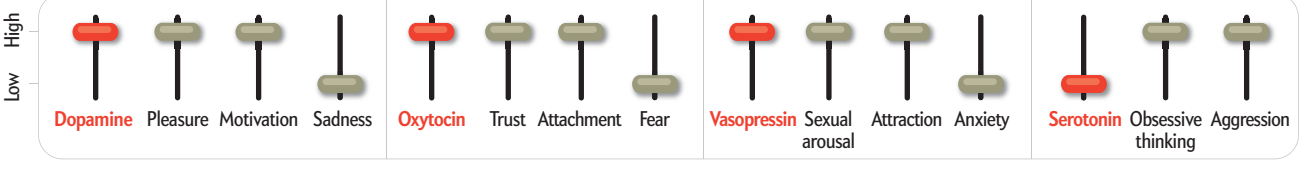
Blood levels and effects



Heightened cognitive functions

- **Body image** — Sees partner's body as better than own
- **Self-representation** — Sees partner as completing self
- **Attention** — Focuses on partner; ignores others
- **Social cognition** — Understands partner's intentions

Brain chemicals and effects



Men and women can now thank a dozen brain regions for their romantic fervor. Researchers have revealed the fonts of desire by comparing functional MRI studies of people who indicated they were experiencing passionate love, maternal love or unconditional love. Together, the regions release neurotransmitters and other chemicals in the brain and blood that prompt greater euphoric sensations such as attraction and pleasure. Conversely, psychiatrists might someday help individuals who become dangerously depressed after a heartbreak by adjusting those chemicals.

MORE VIEWS OF THE BRAIN IN LOVE
ScientificAmerican.com/feb2011/graphic-science

Passion also heightens several cognitive functions, as the brain regions and chemicals surge. "It's all about how that network interacts," says Stephanie Ortigue, an assistant professor of psychology at Syracuse University, who led the study. The cognitive functions, in turn, "are triggers that fully activate the love network." Tell that to your sweetheart on Valentine's Day.

—Mark Fischetti

Graphics by James W. Lewis, West Virginia University (brain), *and Jen Christiansen*

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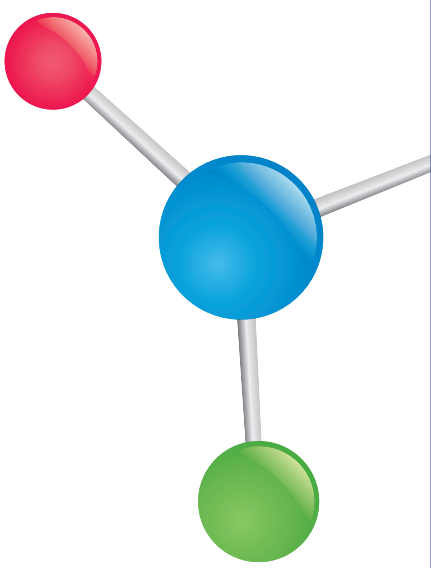
Submit your experiment by April 4, 2011.



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